519

TRANSACTIONS

OF THE

AMERICAN SOCIETY

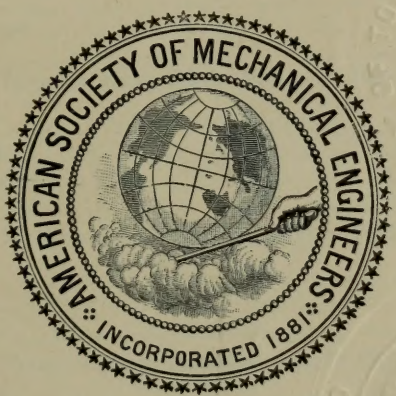
OF

MECHANICAL ENGINEERS.

VOL. XIV.

XXVIth Meeting, New York City, December, 1892.
XXVIIth Meeting, Chicago, Ills., August, 1893,

[*which was also the Sessions of the Section B of Mechanical Engineering of the World's Columbian Congress of Engineering.*]



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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

1892—1893,

FORMING THE STATUTORY COUNCIL.

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E. D. Leavitt	1882—1883	Cambridgeport, Mass.
John E. Sweet	1883—1884	Syracuse, N. Y.
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Henry R. Towne	1888—1889	Stamford, Conn.
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Robert W. Hunt	1890—1891	Chicago, Ill.
Charles H. Loring	1891—1892	Brooklyn, N. Y.

[Note.—The former Presidents of the Society are members of the Council for life or during their retention of active membership in the Society.]

PAST OFFICERS.

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E. D. LEAVITT, JR.	"	Nov. 3d, 1882—Nov. 3d, 1883.
JOHN E. SWEET	"	Nov. 3d, 1883—Nov. 7th, 1884.
J. F. HOLLOWAY	"	Nov. 7th, 1884—Nov. 13th, 1885.
COLEMAN SELLERS	"	Nov. 13th, 1885—Dec. 2d, 1886.
GEO. H. BABCOCK	"	Dec. 2d, 1886—Dec. 1st, 1887.
HORACE SEE	"	Dec. 1st, 1887—Oct. 18th, 1888.
HENRY R. TOWNE	"	Oct. 18th, 1888—Nov. 22d, 1889.
OBERLIN SMITH	"	Nov. 22d, 1889—Nov. 14th, 1890.
ROBT. W. HUNT	"	Nov. 14th, 1890—Nov. 20th, 1891.
CHAS. H. LORING	"	Nov. 19th, 1891—Nov. 29th, 1892.
LYCURGUS B. MOORE	*Treasurer*	April 7th, 1880—Dec. 2d, 1881.
" " "	*Acting-Sec'y*	April 7th, 1880—Nov. 4th, 1880.
THOS. WHITESIDE RAE	*Secretary*	Nov. 4th, 1880—March 1st, 1883.
CHAS. W. COPELAND	*Treasurer*	Dec. 2d, 1881—Nov. 7th, 1884.

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NOTE.

The unusual bulk of the Volume of *Transactions* for 1893 by reason of the number of papers presented at the Engineering Congress in the Mechanical Section, has induced the Publication Committee to omit the full list of members of the Society from the preliminary matter therein. The list which would appear if published here, is that which was corrected up to July, 1893, and was issued as a second edition of the Nineteenth Catalogue. The following summary records the numbers of members in each grade :

Honorary Members	17
Members	1318
Associates	73
Juniors	229
Total	1637
Life Members	54

AMENDED.

[*November 19th*, 1889—*November 17th*, 1891.]

RULES

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[*Adopted November 5th*, 1884.]

OBJECTS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

MEMBERSHIP.

ART. 2. The Society shall consist of Members, Honorary Members, Associates and Juniors.

ART. 3. Mechanical, Civil, Military, Mining, Metallurgical and Naval Engineers and Architects may be candidates for membership in this Society.

ART. 4. To be eligible as a *Member*, the candidate must have been so connected with some of the above-specified professions as to be considered, in the opinion of the Council, competent to take charge of work in his department, either as a designer or constructor, or else he must have been connected with the same as a teacher.

ART. 5. *Honorary Members*, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence who have virtually retired from practice.

ART. 6. To be eligible as an *Associate*, the candidate must have such a knowledge of or connection with applied science as qualifies him, in the opinion of the Council, to co-operate with engineers in the advancement of professional knowledge.

ART. 7. To be eligible as a *Junior*, the candidate must have been in the practice of engineering for at least two years, or he must be a graduate of an engineering school.

The term "Junior" applies to the professional experience, and not to the age of the candidate. Juniors may become eligible to membership.

ART. 8. All Members and Associates shall be equally entitled to the privileges of membership. Honorary Members and Juniors shall not be entitled to vote nor to be members of the Council.

ELECTION OF MEMBERS.

ART. 9. Every candidate for admission to the Society, excepting candidates for honorary membership, must be proposed by at least three members, or members and associates, to whom he must be personally known, and he must be seconded by two others. The proposal must be accompanied by a statement in writing by the candidate of the grounds of his application for election, including an account of his professional experience, and an agreement that he will conform to the requirements of membership if elected.

ART. 10. All such applications and proposals must be received and acted upon by the Council at least thirty days before a regular meeting, when the Secretary shall at once mail to each member and associate, in the form of a letter ballot, the names of candidates recommended by the Council for election.

ART. 11. Any member or associate entitled to vote may erase the name of any candidate, and may, at his option, return to the Secretary such ballot enclosed in two envelopes, the inner one to be blank and the outer one endorsed by the voter.

ART. 12. The rejection of any candidate for admission as member, associate, or junior, by *seven* voters, shall defeat the election of said candidate. The rejection of any candidate for admission as honorary member by *three* voters shall defeat the election of said candidate.

ART. 13. The said blank envelopes shall be opened by the Council at any meeting thereof, and the names of the candidates elected shall be announced in the first ensuing meeting of the Society, and also in the first ensuing list of members. The names of candidates not elected shall neither be announced nor recorded in the proceedings

ART. 14.—Candidates for admission as honorary members shall

not be required to present their claims; those making the nominations shall state the grounds therefor, and shall certify that the nominee will accept if elected. The method of election in other respects shall be the same as in case of other candidates.

ART. 15. All persons elected to the Society, excepting honorary members, must subscribe to the rules and pay to the Treasurer the initiation fee before they can receive certificates of membership. If this is not done within six months of notification of election, the election shall be void.

ART. 16. The proposers of any rejected candidate may, within three months after such rejection, lay before the Council written evidence that an error was then made, and if a reconsideration is granted, another ballot shall be ordered, at which thirteen negative votes shall be required to defeat the candidate.

ART. 17. Persons desiring to change the class of their membership shall be proposed in the same form as described for a new applicant.

FEES AND DUES.

ART. 18. The initiation fees of members and associates shall be $25, and their annual dues shall be $15, payable in advance. The initiation fee of juniors shall be $15, and their annual dues $10, payable in advance. A junior, being promoted to full membership, shall pay an additional initiation fee of $10. Any member or associate may become, by the payment of $200 at any one time, a life member or associate, and shall not be liable thereafter to annual dues.

ART. 19. Any member, associate or junior, in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members, when in arrears for one year. Such person may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

OFFICERS.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers and a Treasurer, who shall also be the Trustees of the Society.

All past (Ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council

and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to the approval of a majority of the Council, subsequently given in writing to the Secretary and recorded by him with the minutes. Absent members of the Council may vote by proxy upon subjects stated in the call for a meeting, said proxy to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three Committees.

ART. 28.—The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, to decide which shall be published in the *Transactions*, and which shall be read in full at the meetings.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ELECTION OF OFFICERS.

ART. 31. At the regular meeting preceding the annual meeting a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent nominating committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being un-

derstood that the assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Thursday in November of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

ART. 37. Special meetings may be called whenever the council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

AMENDMENTS.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

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PAPERS

OF THE

NEW YORK MEETING

(XXVIth)

NOVEMBER, 1892.

BEING ALSO THE THIRTEENTH ANNUAL MEETING OF THE SOCIETY.

DII.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XXVIth)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

November 29th to December 2d, 1892.

LOCAL COMMITTEE: ALLAN STIRLING, *Chairman;* H. A. Bang, W. S. Doran, W. H. Fletcher, F. R. Hutton, C. W. Nason, and H. de B. Parsons.

FIRST DAY. TUESDAY, NOVEMBER 29TH.

THE XXVIth Meeting of the American Society of Mechanical Engineers, which was also its Thirteenth Annual Meeting, was convened in the City of New York pursuant to call. The business sessions were held in the house occupied by the Society as tenants of the Mechanical Engineers Library Association. The opening session, which was a gentlemen's evening, was called to order at half past eight, in the cosey auditorium of the house, by Chas. H. Loring, President, who delivered his Annual Address, entitled "The Steam Engine in Modern Civilization." At the close of this address a light collation was served in the supper room, and the rest of the evening was given over to smoking and social reunion of the members, about three hundred of whom were present.

Before session was adjourned, the tellers to count the ballots for the officers for the ensuing year were appointed by the President, under Art. 34 of the Rules, and were Mr. James Hartness and Mr. John H. Webster.

Second Day. Wednesday, November 30th.

The first session for business was convened in the auditorium of the Society's house, 12 West Thirty-first Street, at 10 A.M.

The Secretary's register at headquarters showed the following members in attendance during the Convention:

Alberger, Louis R ..... New York City.
Almirall, Juan Antonio ..... Brooklyn, N. Y.
Archer, Edward R. ..... Richmond, Va.
Babbitt, Geo. Rodney ..... Providence, R. I.
Babcock, Geo. H. ..... New York City.
Baker, W. S. G. ..... Baltimore, Md.
Bagaley, Ralph ..... Pittsburgh, Pa.
Baldwin, Stephen W ..... New York City.
Ball, Frank H. ..... New York City.
Bancroft, J. Sellers ..... Philadelphia, Pa.
Bang, Henry A ..... Trenton, N. J.
Barnes, Abel T. ..... Jamaica Plain, Mass.
Barr, Harry P. ..... Boston, Mass.
Beach, Giles ..... Chicago, Ill.
Beardsley, Arthur ..... Swarthmore, Pa.
Betts, William ..... Wilmington, Del.
Billings, Chas. E ..... Hartford, Conn.
Binsse, Henry L. ..... Newark, N. J.
Bird, W. W. ..... Cambridgeport, Mass.
Birkinbine, John ..... Philadelphia, Pa.
Bissell, Geo. W. ..... Ames, Ia.
Blankenship, R. M ..... Richmond, Va.
Boenig, Rob't W ..... Brooklyn, N. Y.
Bole, Wm. A. ..... Pittsburgh, Pa.
Boyd, John T. ..... Erie, Pa.
Breckenridge, L. P ..... Lansing, Mich.
Bristol, W. H ..... Hoboken, N. J.
Brooks, Edwin C ..... Cambridge, Mass.
Bulkley, Henry W. ..... New York City.
Burns, A. L. ..... New York City.
Buttolph, Benj. J. ..... Providence, R. I.
Caldwell, A. J. ..... New York City.
Campbell, Andrew C. ..... Waterbury, Conn.
Carter, Vaulx ..... New York City.
Cartwright, Robert ..... Rochester, N. Y.
Cassier, Louis ..... New York City.
Christensen, August C. ..... Buffalo, N. Y.
Christie, W. W ..... New York City.
Church, Wm. Lee ..... Boston, Mass.
Clark, Walter L. ..... New York City.
Clarke, S. J. ..... New York City.
Cole, Francis J. ..... Baltimore, Md.

Conover, Edwin K.....New York City.
Cooper, Henry R.....Syracuse, N. Y.
Corbett, Chas. H.....Brooklyn, N. Y.
Cowan, Freeman B.....Painted Post, N. Y.
Creelman, Wm. J.....New York City.
Cremer, James M.....So. Brooklyn, N. Y.
Cronise, E. S.....New York City.
Cruikshank, Barton.....New York City.
Cullingworth, Geo. R.....New York City.
Darling, Edward A.....New York City.
Davis, David P.....New York City.
Davis, E. F. C.....Richmond, Va.
Davis, Isaac H.....New York City.
Denton, James E.....Hoboken, N. J.
Dewson, Edward H., Jr.....Quincy, Mass.
Dick, John.....Meadville, Pa.
Dinkel, Geo., Jr.....Jersey City, N. J.
Dixon, W. F.....Paterson, N. J.
Dodge, James M.....Philadelphia, Pa.
Dodge, W. H.....Mishawaka, Ind.
Doran, Wm. S.....New York City.
Draper, T. Waln Morgan.....New York City.
Du Bosque, F. L.....So. Orange, N. J.
Durand, Wm. F.....Ithaca, N. Y.
Durfee, W. F.....New Brighton, N. Y.
Earll, C. J.....New York City.
Edwards, V. E.....Worcester, Mass.
Egleston, Thomas.....New York City.
Emery, Chas. E.....New York City.
Engel, L. G.....Brooklyn, N. Y.
Faber du Faur, A.....New York City.
Ferguson, Geo. R.....East Orange, N. J.
Fladd, F. C.....Brooklyn, N. Y.
Flagg, S. G., Jr.....Philadelphia, Pa.
Fletcher, Andrew.....New York City.
Forbes, Wm. D.....Hoboken, N. J.
Fowler, Geo. L.....New York City.
Freeman, John R.....Boston, Mass.
Fritz, John.....Bethlehem, Pa.
Fry, Chas. A.....New York City.
Galloupe, Francis E.....Boston, Mass.
Gantt, Henry L.....Philadelphia, Pa.
Giles, C. E.....Providence, R. I.
Gillis, A. R.....Syracuse, N. Y.
Gobeille, J. L.....Cleveland, O.
Goodell, J. M.....New York City.
Goss, W. F. M.....Lafayette, Ind.
Goubert, A. A.....New York City.
Gould, W. V.....New York City.
Granger, A. S.....New York City.
Graves, Irwin.....Camden, N. J.

Gray, G. A. ..... Cincinnati, O.
Green, S. M. ..... Holyoke, Mass.
Greenwood, P. F. ..... Richmond, Va.
Gregory, Wm. ..... Brooklyn, N. Y.
Hague, Charles A. ..... New York City.
Hallock, J. K ..... Erie, Pa.
Hammett, H. G ..... Troy, N. Y.
Hart, F. L. ..... New York City.
Hartness, James ..... Springfield, Vt.
Hawkins, John T. ..... Taunton, Mass.
Hayward, Fred. H. ..... New York City.
Hayward, H. S. ..... Jersey City, N. J.
Henderson, Alexander ..... Boston, Mass.
Henning, Gus ..... New York City.
Hibbard, H. D. ..... High Bridge, N. J.
Hildreth, R. W. ..... New York City
Hill, W. E. ..... Brooklyn, N. Y.
Hill, William ..... Collinsville, Conn.
Hill, Geo ..... New York City.
Hillmann, Gustav ..... Brooklyn, N. Y.
Hoffecker, W. L. ..... Elizabeth, N. J.
Holland, John ..... Dover, N. H.
Holloway, J. F ..... New York City.
Hough, D. L. ..... Camden, N. J.
Humphrey, John ..... Keene, N. H.
Hunt, A. E. ..... Pittsburgh, Pa.
Hunt, R. W. ..... Chicago, Ill.
Hunt, C. W. ..... New York City.
Huson, W. S ..... Taunton, Mass.
Hutton, Fred'k R. (*Secretary*) ..... New York City.
Hyde, C. E. ..... Bath, Me.
Idell, Frank E. ..... New York City.
Jacobi, A. W. ..... Newark, N. J.
Jacobus, D. S. ..... Hoboken, N. J.
Jenks, W. H ..... Brookeville, Pa.
Kafer, J. C. ..... New York City.
Kent, E. C. ..... Bethlehem, Pa.
Kent, Wm. ..... New York City.
Kerr, Walter C. ..... New York City.
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Le Van, W. B. ..... Philadelphia, Pa.
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Longnecker, C. K. ..... Painted Post, N. Y.

Lord, H. F.....Yonkers, N. Y.
Loring, Chas. H. (*President*).....Brooklyn, N. Y.
Low, Fred. R.....New York City.
Lowe, Wm. V.....Fitchburg, Mass.
Lyall, Wm. L.....New York City.
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McElroy, Samuel.....New York City.
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Main, Chas. T.....Providence, R. I.
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Matlack, J. R.....Philadelphia, Pa.
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Mayo, J. B.....New York City.
Mellin, C. J.....Richmond, Va.
Merriam, H. P.....New York City.
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Miller, Alexander.....New York City.
Miller, E. F.....Cambridgeport, Mass.
Miller, Fred. J.....New York City.
Miller, Spencer.....New York City.
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Montgomery, H. M.....New York City.
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Moore, E. L.....Grand Rivers, Ky.
Moore, L. B.....New York City.
Moore, M. F.....Elizabeth, N. J.
Morgan, Chas. H.....Worcester, Mass.
Morison, Geo. S.....Chicago, Ill.
Mumford, E. H.....Brooklyn, N. Y.
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Nicoll, Chas. H.....Newark, N. J.
Nordland, L.....Medford, Mass.
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Norris, J. Van A.....Wilkesbarre, Pa.
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Parsons, H. de B.....New York City.
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Peabody, C. E.....Boston, Mass.
Pearson, Wm. A.....Scranton, Pa.
Peek, Geo. M.....Charlotteville, Va.
Pentz, A. D.....Elizabeth, N. J.
Phillips, Franklin.....Newark, N. J.
Pickering, Thomas R.....Portland, Conn.
Pitman, Stephen Minot.....Philadelphia, Pa.
Platt, John.....Riverton, N. J.
Platt, Jos. C.....Waterford, Conn.

Pollock, James.....Wilkesbarre, Pa.
Pomeroy, L. R.....New York City.
Ponten, Anders.....New York City.
Pratt, Francis A.....Hartford, Conn.
Rand, Addison C.....New York City.
Raque, P. E.....Jersey City, N. J.
Raynal, Alfred H.....Elizabeth, N. J.
Redwood, I. I.....Brooklyn, N. Y.
Rice, Richard H.....Providence, R. I.
Richards, Charles R.....Brooklyn, N. Y.
Richards, Francis H.....Hartford, Conn.
Richards, Frank.....New York City.
Richmond, George.....New York City.
Rickson, C. E.....Brooklyn, N. Y.
Ridsdale, T. W.....Brooklyn, N. Y.
Riesenberger, Adam.....Hoboken, N. J.
Rites, Francis M.....Pittsburgh, Pa.
Roberts, Edw. P.....Cleveland, Ohio.
Roberts, William.....Waltham, Mass.
Robinson, J. M.....New York City.
Rockwood, George I.....Chicago, Ill.
Roelker, H. B.....New York City.
Rogers, W. S.....Troy, N. Y.
Ross, C. G.....Rutland, Vt.
Ross, E. L.....Indian Orchard, Mass.
Rowland, A. E.....New Haven, Conn.
Rowland, Chas. B.....Brooklyn, N. Y.
Rowland, George.....Brooklyn, N. Y.
Rowland, Thomas F.....Brooklyn, N. Y.
Russell, C. M.....Massillon, Ohio.
Sattler, Wm. R.....Elizabeth, N. J.
Scholl, Julian S.....New York City.
Schutte, Louis.....Philadelphia, Pa.
Schwanhausser, William.....Brooklyn, N. Y.
Scott, Walter W.....Jersey City, N. J.
Sewall, M. W.....New York City.
Sharp, Joel.....Salem, Ohio.
Sinclair, Angus.....New York City.
Sinclair, Geo. M.....Philadelphia, Pa.
Smith, Jesse M.....Detroit, Mich.
Smith, Oberlin.....Bridgeton, N. J.
Snell, Henry I.....Philadelphia, Pa.
Spaulding, H. C.....Exeter, N. H.
Sperry, Charles.....New York City.
Spies, Albert.....New York City.
Stangland, B. F.....New York City.
Stanton, John.....New York City.
Stearns, Albert.....Brooklyn, N. Y.
Stevens, J. F.....Philadelphia, Pa.
Stillman, Frances H.....Brooklyn, N. Y.
Stirling, Allen.....New York City.

Stratton, W. H.	Providence, R. I.
Strobel, Victor O.	Philadelphia, Pa.
Strong, Geo. S.	New York City.
Suplee, H. H.	Stamford, Conn.
Swasey, Ambrose	Cleveland, Ohio.
Sweet, John E.	Syracuse, N. Y.
Swenson, Wathier	New York City.
Tabor, Harris	Elizabeth, N. J.
Taylor, John T.	New York City.
Taylor, Stevenson	New York City.
Thomas, Charles W.	New York City.
Thomson, John	Brooklyn, N. Y.
Thurston, Robert H.	Ithaca, N. Y.
Torrey, Herbert Gray	Stirling, N. J.
Towne, Henry R.	Stamford, Conn.
Trask, G. F. D.	Philadelphia, Pa.
Trautwein, A. P.	Carbondale, Pa.
Trowbridge, Amasa	Middletown, Conn.
Tucker, Wm. B.	Elizabeth, N. J.
Ulmann, Charles J.	New York City.
Underwood, F. H	Tolland, Conn.
Varney, Wm. W.	Baltimore, Md.
Victorin, Anthony	West Troy, N. Y.
Voorhees, Philip R.	New York City.
Walker, John.	Cleveland, Ohio.
Walworth, A. C.	Boston, Mass.
Ward, W. E.	Port Chester, N. Y.
Warren, B. H	Stamford, Conn.
Webster, John H.	Boston, Mass.
Webster, Wm. R.	Philadelphia, Pa.
Weeks, Geo. W.	Clinton, Mass.
Weickel, Henry	Stamford, Conn.
Wellington, A. M.	New York City.
Wellman, Samuel T.	Cleveland, Ohio.
Wheeler, F. M.	New York City.
Wheeler, S. S.	New York City.
White, Maunsel	Bethlehem, Pa.
Whitehead, Geo. E.	Providence, R. I.
Whitney, Baxter D.	Winchendon, Mass.
Whitney, Wm. M.	Winchendon, Mass.
Wiley, William H. (*Treasurer*)	New York City.
Winship, J. G.	New York City.
Wood, De Volson	Hoboken, N. J.
Wood, Matt. P.	New York City.
Woodbury, C. J. H.	Boston, Mass.
Woolson, O. C.	Newark, N. J.
Wright, Louis S.	Philadelphia, Pa.
Wright, J. Q.	Fitchburg, Mass.
Total	294

There was also a number of guests present, and the usual large delegation of ladies.

The first order of business was the report of the Council, presented by the Secretary, as follows :

ANNUAL REPORT OF THE COUNCIL.

The Council of the American Society of Mechanical Engineers begs leave to present its Annual Report as follows :

Seven meetings have been held during the year for the transaction of business, and the following is a summary of the action taken, in addition to the usual routine of passing upon applications for membership.

Applications have been received from a number of Technical institutions requesting that their libraries might be put upon the free list of those who are to receive the volume of *Transactions* gratuitously as issued each year.

These requests have been granted in the case of institutions which, by their charter, give the degree of Engineer, and in many cases sets of back volumes have been forwarded at the usual member's rate of half that at which the volume can be purchased by outsiders.

The Council has considered favorably a suggestion that there be kept on file in the Society's house a record of the patents which had been taken out by its members, and that, where practicable, copies of the letters patent be obtained, accompanied by models or samples where an exhibition of this sort could be made available.

The Council has further accepted a proposition made by the World's Congress Auxiliary, that the American Society of Mechanical Engineers should undertake the responsibility for the management of the details of the Mechanical Engineering Section of the Congress, to be known as Division "B."

The Council therefore urges upon the members the importance of co-operating in making this department of the undertaking a notable success, particularly as the Council has further directed, in carrying out the intent of this proposition, that the regular meeting falling in the spring of 1893 should be moved forward to coincide with the date of the Congress, which thus becomes the Twenty-seventh Meeting of the Society.

A proposition has been received that American engineers be requested to co-operate in the recognition which is to be shown

at Colmar, Alsace, the native place of G. A. Hirn, deceased honorary member of this Society. The commemoration will take the form of a monument, and the attention of the members of the Society has been called to the matter in open convention, so that any one who desired might have a chance to subscribe.

The Society rooms have been enriched by the gift, during the year, of a handsome crayon portrait of the late John C. Hoadley, member of the Society, and by a photograph of the late Geo. H. Corliss.

Suitable recognition has been made to the widows of these eminent engineers, who have thus remembered the profession in which they acquired their fame. A handsome upright piano has also been added to the furniture of the reception parlor, by the generous interest of a syndicate of members. It adds much to the pleasure of visitors to the house.

The rental which is paid by the American Society of Mechanical Engineers has been raised by vote of the Council, pursuant to a request of the landlords, the Mechanical Engineers Library Association, from the sum of $2,200 to $3,000 per annum, in view of the considerably increased accommodations enjoyed by the Society over those which had been planned when their arrangements were first made.

By gift of Mr. Carleton W. Nason, a bulletin board has been put up in the corridor of the house, in order that suitable entry might be made thereon of the members removed by death during the Society year. From the same generous hand also a handsome pedestal and marble bust of the late Joseph Nason have been received as a gift to the Society.

The matter has been under advisement to provide in 1893 for showing suitable courtesies to the visiting engineers from Europe who might be passing through the country on their way to Chicago. The Council has considered that two separate obligations lay upon the engineers of America, and they have appointed two committees to consider these obligations as two separate questions.

The first committee was to confer with the representatives of the other engineering societies as to the courtesies which should be extended by the profession of engineering to all the representatives of the profession who might visit America in 1893, coming from all parts of Europe. This committee, after holding several meetings in conference with the committees of the sister societies, has reported to the Council the opinion of the Conference Committee,

that each Society should show in its own way the courtesies which might be practicable in the house of each Society, but that it did not seem advisable to take joint action looking to the maintenance of a special headquarters in New York to be carried on at the expense of all the societies participating.

This Society will therefore arrange for a special effort of its own to tender in its own house all possible service to the foreign visitors, by having in continuous attendance a person competent to converse in the usual languages of Europe, and able to give information as to railway journeys, itineraries, hotels, etc., as may be found convenient and possible. This work will be in the hands of a special committee appointed for this purpose.

The second committee was appointed to consider what special return of courtesies it might be possible to show to the representatives of the English and French Societies of Civil Engineers, who were the hosts of the representatives of the National Societies in 1889, and for whom these two Societies were the channel through which they were the recipients of special attentions.

This second committee has formulated an invitation to these two Societies to be the object of especial courtesies if they will visit this country in a body, the details of which will be a matter of later announcement.

The Committee of the Society formed at the request of the Committee on Awards of the World's Columbian Exposition, to recommend a method and system for conducting the tests upon machinery, engines, and boilers exhibited, has presented its report. The report of this committee is to be appended to the Proceedings of this meeting.

In the matter of maintaining at Chicago, in connection with the other engineering societies, a headquarters for the use of the members of the societies and their guests, a circular was issued to the members inviting subscriptions, and during the year replies have come bringing the amount of this subscription up to $1,500.

It is obviously necessary that another effort be made to raise this sum more nearly to the quota of $3,000 which is likely to be called for from this Society.

On August 21, 1892, Mr. John Fritz, a former Vice-President of this Society, reached his 70th birthday, and the Council directed that a suitable congratulatory message be forwarded to him in the name of the Council on this occasion. A copy of this minute is appended to this report.

In view of the embarrassment and loss which must sometimes come to the Society, when, by reason of advancing years, persons of distinguished standing in the profession, and for a long time members of the Society, may find that the demand for the yearly dues becomes a burden, and by reason of the fact that the honorary membership is of necessity restricted, the Council proposed that there be made the following amendment to the rules, and notice of it is hereby given under the provision for such amendments. It is proposed to add to Article 18 the following sentence:

"The Council shall, in its discretion, have the power, by unanimous vote at a regular meeting, to remit in whole or in part the fee for life membership in the case of any person who shall have been for not less than ten years a full member or associate in good standing."

The Council has passed favorably during the year upon 180 applications for membership in the several grades.

Losses by resignation during the year number twenty-one, of which but a very small number could be traced to the effect of the increased dues.

Losses by death were as follows:

Geo. H. Bleloch,	Edgar M. Bixby,	J. Archie Taylor,
H. P. Minot,	Geo. M. Copeland,	W. P. Trowbridge,
W. H. E. Grant,	J. W. Tynan,	J. W. Handron,
Edward M. Reed,	Jas. Mahoney,	Jas. Morgan.
Thos. Wilbraham,	W. H. Worthen,	
Sir John Goode, Hon. Member,	Geo. S. Percival,	
	John A. Price,	

The present membership, including those elected at this meeting and favorably acted upon by the voting membership, is 1,569, and is distributed among the grades as follows:

Honorary membership	17
Life membership	39
Full membership	1,273
Associates	68
Juniors	211
Total	1,569

The Council would also present the report of its Tellers of Election as follows:

REPORT OF THE TELLERS OF ELECTION.

The undersigned were appointed a Committee of the Council to act as tellers (under Rule 13), to scrutinize and count the ballots cast for and against the candidates proposed for membership

in the American Society of Mechanical Engineers, and seeking election before the XXVIth Meeting, New York, 1892.

They have met upon the designated days, in the office of the Society, and have proceeded to discharge their duty. They would certify for formal insertion in the records of the Society to the persons whose names appear on the appended list to their respective grades.

There were 527 votes cast of the green ballot, of which 13 were thrown out because of informalities (the members voting having failed to indorse the sealed envelope).

STEPHEN W. BALDWIN,
CARLETON W. NASON, } *Tellers.*

There were 483 votes cast on the blue ballot, of which 23 were thrown out, the voter not having affixed his name thereto.

STEPHEN W. BALDWIN,
CARLETON W. NASON, } *Tellers.*

MEMBERS.

Bradley, William H.,	Flinn, Thomas F.,	Matlack, John R., Jr.,
Benet, Laurence V.,	Fry, Alfred Brooks,	Mattsson, A. George,
Butcher, Joseph John,	Foster, Theodore Reno,	Messenger, Frank M.,
Bayles, Robert Nelson,	Fries, Axel H.,	Munton, James,
Benjamin, Charles Henry,	Granger, Albert Sanford,	Macdonald, Wm. R.,
Brush, Charles B.,	Greenleaf, Geo. Edw.,	Macomber, Irwin John,
Bryan, Kennerley,	Greensmith, Jas. E.,	Noble, Patrick,
Browne, Thomas Reath,	Gaskin, Edw. F. W.,	Phelps, Frederick A.,
Bosson, Frederick N.,	Green, Wm. Henry,	Phipps, C. W.,
Boyd, Henry A.,	Henderson, John Carlos,	Quereau, C. H.,
Chase, Harvey Stewart,	Hyman, D.,	Rumley, J. G. M.,
Cloudsley, James B.,	Heckendorn, H. C.,	Ricketts, Palmer C.,
Campbell, Harry Huse,	Jessen, Jacob,	Seymour, James A.,
Canfield, Hobart,	Jones, Albert I.,	Scheffler, Theo. F.,
Churchill, William W.,	Johnson, Edw. Willis,	Stut, John C. H.,
Davis, Louis Ketcham,	Jefferies, E. A. W.,	Stanton, Frank McMillan,
Donkin, Bryan, Jr.,	Kerr, C. V.,	Ward, Charles,
Dowst, F. B.,	Knight, Albert Franklin,	Wells, Frederick L.,
Du Bosque, F. L.,	Lewis, David J., Jr.,	White, Samuel K.
Engel, G.,	Lane, Almeron Mark,	
Earll, Charles Isaac,	Logan, John D.,	

ASSOCIATES.

Crowell, Hilen Canfield,	Goodell, John Milton,	McKee, Joseph J.,
Ferry, Chas. H.,	Hyde, John Sedgwick,	Wiley, W. O.

PROMOTIONS TO FULL MEMBERSHIP.

Aborn, Geo. Pennell,	Hough, David L.,	Stangland, B. F.

JUNIORS.

Bradley, Joseph.	Dyer, Robert M.,	Parker, Austin W.,
Bump, Burton Nelson,	Guilford, Wm. Moore, Jr.,	Pomeroy, Harry D.,
Bossert, Chas. Philip,	Hoyt, Carrol Livingston,	Rearick, Chas. Bemis,
Carter, Henry W.,	Knox, S. L. G.,	Riggs, John D.,
Cromwell, J. C.,	Mayo, John B.,	Steele, Walter D.,
Cawley, Frank,	Mahl, Fred. W.,	Sewell, James G. C.,
Darren, David H.,	Nordland, Lawrence,	Smith, Howard W.,
Davis, Francis D.,	Peek, Geo. Meredith,	Wallace, David A.

APPENDIX TO REPORT OF COUNCIL—LETTER TO JOHN FRITZ.

Congratulatory. 1822–1892.

In honor and respect of our esteemed member and ex-President, John Fritz, who after long years of active duty as a mechanical engineer, and as a noted captain of industry, seeks a rest well earned; whose ever-busy life began almost contemporary with the manufacture of iron in our country, who through all its advancing stages imprinted upon it the marks of his thoughtful labors, who with his friend Holley stood beside the cradle of the newly born industry of steel-making in the United States, by the Bessemer and kindred processes, promoting its growth by his wide and varied experience, and crowning its highest achievements with the versatility of his genius and his rare good judgment, the Council of the American Society of Mechanical Engineers desire to make this minute.

Endeared as he is to us individually, and to the Society we represent, we cannot permit this eventful occasion to pass without tendering to him our love and respect, and without joining in a hearty wish for his future health and happiness, and without expressing the earnest hope that for years to come we may be aided by his counsel and encouraged by his genial good fellowship.

Believing that his great warm heart will receive this slight tribute in the spirit in which it is tendered, we have the honor to subscribe ourselves the loving friends of John Fritz, of Bethlehem.

On behalf of the Council:

Stephen W. Baldwin,
Carleton W. Nason,
Andrew Fletcher,
W. A. Perry,
J. E. Denton,
John Thomson

On behalf of the Honorary Councillors:

J. F. Holloway,
Geo. H. Babcock,
Robert W. Hunt,
Horace See.

Chas. H. Loring, *President.*
F. R. Hutton, *Secretary.*
Wm. H. Wiley, *Treasurer.*

New York City, *Aug.* 21, 1892.

REPLY OF MR. JOHN FRITZ.

To the Council of the American Society of Mechanical Engineers, No. 12 West 31st St., New York City.

Esteemed Friends: You well know that writing letters and making speeches is not my forte, but after the beautiful and kindly manner in which you have been pleased to congratulate me on the event of my seventieth birthday, I cannot remain silent. Permit me to say to you, and through you to my kind friends in the Society you represent, that I appreciate the compliment you bestow upon me to the greatest extent; that I look upon its possession as one of the happiest events of my life, and one of which I shall ever be proud. As a bare-footed boy, following the plow from early morn to late at night, I little dreamed that at some future time I would be the recipient of such an honor, and be surrounded by so many kind and thoughtful friends. Often during my career, when burdened with trials, anxieties, doubts, and disappointments, I have felt that life was not worth the fight I was engaged in, and had it not been unmanly I would have stepped down and out; but taking courage again, I struggled onward, and now that my life is nearing the end, I cannot express to you how happy I am to receive such a token of your esteem, and to be assured that my efforts to do the best I could have been appreciated by a class of men so eminently qualified to sit in judgment on what I have done, and to be also assured, as I am by what you have so kindly said, that my life was not lived in vain. I know of no higher reward that can come to any man than to receive at such a time in his life such hearty, heartfelt congratulations from his friends, neighbors, and associates, and I only wish I could better express to you all how grateful and thankful I am, as I look upon your beautiful Congratulatory, now adorning my walls, and bearing as it does the names of some of my dearest friends; but I can only repeat what I tried to say at the beginning, give to the Society we all so much love, and to the gentlemen to whom you assigned the labor of preparing the gift, the grateful thanks of their friend, and your friend,

John Fritz.

Bethlehem, Pa., *Aug.* 26, 1892.

At the close of the Report of the Council the second order of business was the Report of the Finance Committee, which was as follows:

The Finance Committee of the American Society of Mechanical Engineers would respectfully report to the Council the following statement of the receipts and expenditures, on behalf of the Society, under their direction, during the Society year from November, 1891, to November, 1892.

ANNUAL REPORT.

Receipts.

Initiation Fees	$3,880 00
Annual Dues, Current	19,630 83
" " Past	323 00
" " Advance	107 60
Paper Sales	2,842 23
Binding	151 50
Badges	807 45
Engraving	323 85
Rent of Hall and Parlor	465 00
Life Membership: Bonds Surrendered	3,900 00
" " Cash	1,050 00
Profit and Loss	7 00
Gift, Bonds	500 00
Postage and Express	37 83
Interest on Investment	80 00
" " Balance in Savings Bank	86 30
Balance on Hand, Nov. 1, 1891	2 00
Total Receipts	$34,195 09

Expenditures.

Printing and Stationery	$2,123 25
Publications	9,955 48
Postage and Express	1,198 57
Library	200 75
Salaries	4,322 42
Office Expenses	695 58
Engraving	1,352 35
Contingencies	92 50
Binding	2,107 00
Meetings	658 45
Furniture and Fixtures	261 99
Badges and Certificates	1,160 95
Travelling	245 90
Rent	2,666 65
Work of Committees	177 91
Investment, Bonds Bought	800 00
" Bonds Received for Life Membership	3,900 00
" Gift of Bonds	500 00
Interest on Investments	9 10
" " Savings Bank Deposit	86 30
Cataloguing	25 50
Insurance and Safe Deposit	17 00
Balance in Treasurer's Hands, Nov. 1, 1892	1,628 44
Total	$34,195 09

In explanation and comment on the above, the Committee beg to call the attention of the members to the fact that when the last report was presented, in November, 1891, the dues were ten dollars per annum for members and associates, and five dollars per annum for juniors. At the beginning of the fiscal year just closing, the dues were increased by five dollars per annum for all grades. At the presentation of that report, there were outstanding bills against the Society amounting to $3,586.15, for which there was no money available, as the balance in the treasurer's hands had been drawn down to two dollars.

The total receipts last year were $19,842.62: the total of this years receipts, $34,193.09, shows an increase of over 73%.

As will appear from the report, not only has the entire back indebtedness been obliterated by the receipts of the year, but the Committee have been able to meet the special charges for the reissue of Volumes I., II., and III. of the Society's *Transactions*, which have been exhausted in the earlier edition, which was small and was printed from type only.

Withdrawing from the summary the items, Binding, $130.90; Printing, $3,407.33, to the amount of $3,538.23, which will not occur again, chargeable to this expenditure alone, the financial improvement is made still more apparent, inasmuch as the new edition is printed from plates which are the property of the Society, and constitute an investment from which it may realize in future sales of these volumes.

The receipts from sales of publications are greater this year than usual, by reason of the sale of many copies to members who had subscribed for them.

The receipts from Life Membership account, $4,950, are larger than usual this year by reason of the policy, which is very generous in its relation to the Society, which has been pursued by a number of the members. They have constituted themselves life members by the payment of the two hundred dollars necessary for this purpose, using as a legal tender bonds to that amount of those which were issued for the purchase of the house and lot which the Society occupies. By this means $3,900 worth of these bonds have been acquired, the principal of which surrendered bonds becomes the property of the Society; and as the bonds bear interest, they form a 5% investment during their period, and transfer the second mortgage lien to a greater extent from individuals to the organization. From the surplus the

Committee have also purchased bonds to the extent of eight hundred dollars, making a total of interest-bearing bonds, now in the possession of the Council, as trustees, which have been acquired through this and other means, to the amount of fifty-seven hundred dollars, all of which is interest bearing, save a few bonds, the interest on which is, by the deed of gift, to be paid to the Library Association.

There is also to the credit of the Society, in the Bleecker Street Savings Bank, $1,115.34, and in the Merchants' Clerks' Savings Bank of this city, $1,243.63, an invested fund of $2,358.97, bearing interest, and to be devoted to the purchase of books for the library. It will also be seen that this year the Society has made a comparatively small cash outlay for books, but has acquired over two hundred dollars' worth of books by exchange for sets of its *Transactions*, as reported from the Special Library Committee.

There remains outstanding uncollected dues, for the year just closed, to the amount of $1,396.45, from eighty-nine members. This unusually small percentage in a membership of over fifteen hundred is generally considered phenomenal, and is doubtless due to the fact that the Council have considered the annual dues to be a business and commercial obligation, and have directed that when it remains unpaid and overdue for eleven months the neglectful member shall be drawn upon at sight. This procedure, so usual in commercial circles, is doubtless the reason why so few remain in arrears, since no one is so by oversight, and only those who by reason of ill health or other good cause have requested an extension are those whose accounts remain open.

It speaks well for the healthy interest of all its active members in the Society that this state of affairs can be reported.

Respectfully submitted

By the Finance Committee,

STEPHEN W. BALDWIN,
F. MERIAM WHEELER,
JOHN THOMSON,
J. F. HOLLOWAY,
F. R. HUTTON.

The Secretary then read the

REPORT OF THE LIBRARY AND HOUSE COMMITTEE.

The House Committee, intrusted also with the duties of superintending the interests of the Library, which is leased to the

Mechanical Engineers Library Association as a part of the consideration which passes between the two organizations, beg leave to report that the Society's bedrooms in the third and fourth stories of the house have been made use of to a very considerable extent all through the year, in some cases the demand for this accommodation being in excess of what could be furnished. The movement of having these rooms at the service of non-resident members has been very popular, and will be continued as a feature of the Society's life at the house. The income from this source, which passes to the credit of the Library Association, will be seen from its report of receipts to exceed $1,600.

The reunions held in the house during the winter of '92 were in no sense a Society affair, but carried on by the resident members, who bore the entire expense, although they were under the control of the House Committee, who assumed the burden of looking after their details.

There were also inaugurated the Professional Evenings, for the discussion of topics of interest to engineers, and the subjects under treatment on the various evenings have been, "What do you know about boilers?" "What does your power cost you?" "What rackets have you had with castings?"

The report of the Finance Committee of the Library Association made to the entire Society of the Mechanical Engineers through the channel of the House and Library Committees is appended to this report:

LIBRARY ASSOCIATION.

The summary of receipts and disbursements of the Trustees from November, 1891, to November, 1892, is appended below.

Receipts.

Balance on Hand, November 1, 1891		$901 54
Fellowship Fund	$354 00	
Sinking Fund	648 00	
Library, Permanent	5 00	
" Current	4 00	
Office Rent	3,669 98	
Room "	1,645 85	
Gift	600 00	—6,926 83
		$7,828 37

Disbursements.

Interest on Mortgage	$1,485 00	
" " Bonds	1,605 00	
Salaries	507 50	
Supplies	278 20	
Fuel	234 00	
Lighting	631 95	
Equipment	246 72	
Laundry	141 05	
Binding	188 18	
Repairs	189 33	
Cataloguing	142 05	
Book Purchase	793 77	
Contingencies	10 00	
Investment	600 00	
Cash on Hand, Nov. 1, 1892	775 62	$7,828 37

At the close of the administrative reports, which were accepted and ordered on the records, the Chair called for the reports from the professional committees of the Society.

The Committee on Standard Methods of Test and Testing Materials reported progress. The Committee on Standard Methods of Testing Efficiency of Locomotives also reported progress merely.

The Committee on Standards reported through its Chairman by the following letter:

REPORT COMMITTEE ON STANDARDS.

To the American Society of Mechanical Engineers:

Your Committee on Standards would report that the Bill regarding Standards matter came up in Congress; was referred to Committee on Patents; was argued before the Committee; was looked favorably on by the Committee as far as their expressions went; and the Chairman stated he would report favorably. The report was not made, and the Bill died at the expiration of the Congress. From an investigation of Congressional methods, your Committee is inclined to believe that measures of this kind will not receive satisfactory action by Congress until it has been before them for many years, and hardly then in the case of a measure possessing no more popular interest than the measure in question. Under these circumstances it is believed that the desired results can be more promptly accomplished through the medium of some special association, disconnected from the Government and disconnected from other societies; Governmental adoption of the work following later, when its utility and importance may have been established by the association which inaugurated it. Under these circumstances it is suggested that the Committee be discharged and the matter dropped so far as the Society and Congressional action is concerned. This report is made by the Chairman of the Committee on Standards, without consultation with his colleagues.

Respectfully submitted,

JAMES W. SEE,

Chairman 2d Committee Work.

Mr. Oberlin Smith.—I have not had any conference with Mr. See, the Chairman of our Committee, as he is not a man who is

very easy to reach, and he has sent this report in without the other members of the Committee. So far as I know, the Committee have not done anything for some months past. I leave it, of course, to the Society to say whether the Committee shall be discharged. For myself, I am very much in favor of the measure, and I think most of us are. If anything practical could be done, I should say keep the Committee going. But Mr. See knows more about the Congressional work than any of the rest of us, and has had more experience with it, and his opinion would have great weight with me. If he thinks it had better be dropped for the present, perhaps it had better be. I am not sure whether work of this kind could not be taken up by the new society, the American Institute of Inventors and Manufacturers, which was established in Washington a little over a year ago ; and it is possible that, as they are going to work especially in patent reform, they might carry this thing along with it.

The President.—What is your pleasure about the report?

Prof. Thurston.—I move that the Committee be discharged.

The motion was carried.

The report of the Committee on Standard Units was called for.

The Secretary read a letter from Professor Egleston, resigning the chairmanship of the Committee, and reported the recommendation of the Council that the work of this Committee be discontinued for the present.

On motion the recommendation was accepted and the Committee discharged.

The Secretary read the report of the tellers to count ballots cast for officers, as follows :

REPORT OF TELLERS OF ELECTION, ANNUAL MEETING, NOVEMBER, 1892.

Whole number ballots cast		.449	
For President	Eckley B. Coxe	.448	—scattering 1
" Vice-President	C. W. Hunt	.452	
" "	Thos. R. Pickering	.442	
" "	Edwin Reynolds	.449	— " 4
" Treasurer	W. H. Wiley	.449	
" Manager	Chas. H. Manning	.452	
" "	John Thomson	.446	
" "	C. W. Pusey	.447	

Respectfully submitted,

J. H. WEBSTER,
JAMES HARTNESS, } *Tellers of Election.*

November 30, 1892.

The Chair then called for a report from a representative of the Society on the Joint Committee of Engineers' Societies, intrusted with the consideration of questions relating to a headquarters at Chicago during the Columbian Exposition and the World's Congress of Engineers.

Mr. Jesse M. Smith.—There is not a great deal to be said since the last meeting. A report has just been issued, signed by the General Committee of the World's Congress Auxiliary, which is made up very largely of the committees appointed by the four national engineering societies for that purpose. The report I will read in part: "The affairs of the Engineering Congress are intrusted to a general committee, assisted by the advisory council appointed by the Hon. Charles C. Bonney, president of the Congress Auxiliary." "The General Committee will have the practical control of the organization and proceedings of the general sessions of the Congress. It will determine the general programme of the Congress and the time and place of the division sessions." "All formal invitations to participate in the Congress will be issued by the General Committee, and a formal invitation is to be given to all the engineers of the world. The Congress has been divided into six sections. Division A consists of civil engineering, to be under the charge of the American Society of Civil Engineers, who undertake to provide papers for that section and to assume the management of it. Division B is to be under the control of the American Society of Mechanical Engineers, and the officers of that division are the officers of the Society of Mechanical Engineers for the next year, Professor Hutton being the secretary, as well of that division as of the Society. The division sessions will be organized and controlled by the officers in charge of the divisions. There may be joint sessions of two or more divisions, which will be similarly controlled by the divisions concerned. Correspondence concerning papers and proceedings of any division should be addressed to the representative thereof, and not to the General Committee. In other words, if there are any communications to be made on account of this Congress they are to be made in our division to Professor Hutton. The place of holding the Congress is, of course, Chicago, and the time assigned by the World's Fair Auxiliary is from Monday, July 31st, to Saturday, August 5th, 1893, inclusive. There will be an opening session at ten o'clock on Monday, July 31st, in one of the large halls of the Art Palace now being built in the Lake

Front Park, Chicago. That, most of you know, is not in the Exposition grounds, but in the city. The new building, which is to be an art memorial, is a permanent structure, containing large audience rooms, with several smaller ones where the different sections can have their meetings independent of the other sections. In the large auditorium all the sections can meet together for the first and the last meeting. This art memorial building is on the lake front near Van Buren Street, right in the centre of the city, and near the termini of all of the means of communication between the World's Fair grounds and the city. After appropriate addresses the divisions will convene in their respective session rooms in the same building. Cards of admission to the Engineering Congress will be issued by the secretary of the General Committee, upon the presentation of introductory cards given by the officer in charge of the several divisions or by the officers of the societies invited to participate in the Congress. The cards of admission will entitle the holder to attend the meetings of any session. There will be no entrance fee for participation in the proceedings. The proceedings will consist of the reading and discussion of such papers as shall have been accepted by the management in each division, and according to the rules which may be adopted. It is expected that a number of these papers will be secured and printed early in 1893, so that the copies can be obtained, though not for publication, by those desiring to offer contributions to the discussion. Preference will be given to papers which relate to new and important constructions, machines, processes, methods, experiments, and investigations. It is very desirable that papers be sent in early, that days may be assigned for securing their favorable consideration. Correspondence relating to the time when proposed papers must be transmitted for acceptance should be addressed to the representative of the division concerned in our case, to our own Secretary. The Congress will terminate with a general morning session on Saturday, August 5th, on which day there will be no division sessions. It is contemplated that the entire proceedings of the Engineering Congress will be published and copies sold at cost to engineers who may subscribe for the same, but the societies having the charge and management of divisions will have the right of publishing appropriate portions of the proceedings. All contributions accepted will be subject to the usual control of these societies over their own publications, including the editing of manuscripts,

the determination of typographical style, and the number, style, and kind of engravings, the concurrence of the author being secured on all essential points, and proofs being submitted to him when time permits. This will not interfere with any publication for which the auxiliary may arrange. In other words, Division B is entirely under the control of the Mechanical Engineers, and papers presented to that division will be published in our proceedings as the proceedings of the summer meeting of that year. We have also the right to publish the proceedings, as I understand it, of any other division in our own *Transactions;* and, besides that, the transactions of the whole Congress will be published by the World's Fair Auxiliary, and sold at nominal rates to those who may desire them. After the close of the Engineering Congress it is intended to arrange for excursions to points of engineering interest, particulars of which will be announced later. Arrangements are now in progress for securing the lowest practicable rates of transportation for parties attending the Congress.

A word as to the engineering headquarters, which are being undertaken also by the same committee appointed by the four engineering societies. As I understand it, they have already secured a building, which is on Van Buren Street between Michigan Avenue and Wabash Avenue, a very central location, about a block from the Auditorium Hotel, which will probably be a landmark for most of you. It is just half a block from the Lake Front Park, and of course will be very near the building where the Congress is to be held ; near the station of the Illinois Central Railroad, which is the most direct communication with the World's Fair grounds, and the steamboat landings; and also within a block of the cable road, and within two blocks, I believe, of the elevated road leading to the Exposition ; so that it is a very central location, and the Committee feel that they have secured a very desirable building. They have the use, as I understand, of the third story of the building from the beginning, or as early as they choose to occupy it, and as late as they choose, and the second story of the building they will have from the 1st of May until about the middle of October. There they propose to have large reception rooms, and smaller rooms for committee work and private meetings, and there will be in attendance gentlemen who are familiar with the foreign languages, and who can give information to the foreign engineers as well as our own. I wish to say a word about the contributions which have been already made by some of the

members, and the desire that more be sent in. The expense of this undertaking will certainly be considerable, and while quite a number have already responded liberally, it will still be necessary for others to do so; and I think one of the chief reasons why the response has not been more generous is the lack of information on the subject among the general membership. The Committee, I understand, is to have a meeting in about two weeks from now to complete the arrangements, and will probably issue a circular, which will come to you in due form through the Secretary; but in the meantime, if any are disposed to put their names down, they will find the proper facilities in the hands of the Secretary.

The President.—Gentlemen, this is a very interesting statement of the completeness of the arrangements for the headquarters and the Engineering Congress, but calls for no action if there are no further questions to be asked.

The report of the Society's Committee on Standard Flanges was then presented by its Chairman, Mr. C. W. Nason, and, with the discussion upon it, appears immediately after the Proceedings of the Meeting as a separate paper.

At the close of the Report of the Committee on Standard Flanges, the Secretary presented to the Convention the matter of a standard gauge system for uncoated metallic sheets and plates. The subject has been brought to the notice of the Society by the following letter:

THE PIQUA ROLLING MILL CO., PIQUA, O., *Oct.* 18, 1892.

THE SECRETARY OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Dear Sir: Herewith I enclose you a proposed United States Standard of Gauges for iron and steel sheets.

The Association of Galvanized Manufacturers, the National Iron Roofing Co., and the Association of Iron and Steel Sheet Manufacturers have adopted the enclosed list of gauges and will recommend their adoption by Congress at an early date.

The merits of the gauges proposed are set forth in the copy of letter, also enclosed, from W. C. Cronemeyer, President of the United States Iron and Tin Plate Manufacturing Co., Demmler, Pa.

It is unnecessary, I presume, to enlarge upon the great advantage to all interested of the adoption of a uniform system of measuring iron and steel sheets, it being well known to all conversant with the subject that there are numerous gauges, originated in England, used in this country, and also one American gauge. These conflicting sources of authority are very perplexing, causing numerous lawsuits and disagreements between parties interested in sheet metals.

The undersigned is a member of each of the above associations, and is also

president of the second and third, hence can speak with full authority in the matter as to the action of the associations named.

Kindly advise me if you can comply with the requests herein, and greatly oblige,

Yours very truly,

(Copy.) J. G. BATTELLE.

PROPOSED UNITED STATES STANDARD GAUGES FOR ALL UNCOATED SHEETS AND PLATES OF IRON.

Number of gauge.	Thickness in fractions of an inch.	Thickness in decimal parts of an inch.	Thickness in millimetres.	Weight per square foot in ounces.	Weight per square foot in pounds.	Weight per square foot in kilogrammes.	Weight per square metre in kilogrammes.	Weight per square metre in pounds.
0000000	1-2	.5	12.7	320	20.00	9.072	98.80	217.81
000000	15-32	.46875	11.90625	300	18.75	8.505	92.66	204.28
00000	7-16	.4375	11.1125	280	17.50	7.938	86.45	190.59
0000	13-32	.40625	10.31875	260	16.25	7.371	80.28	176.99
000	3-8	.375	9.525	240	15.	6.804	74.19	163.56
00	11-32	.34375	8.73125	220	13.75	6.237	67.93	149.77
0	5-16	.3125	7.9375	200	12.50	5.67	61.77	136.18
1	9-32	.28125	7.14375	180	11.25	5.103	55.55	122.36
2	17-64	.265625	6.746875	170	10.625	4.82	52.52	115.79
3	1-4	.25	6.35	160	10.	4.536	49.40	108.90
4	15-64	.234375	5.953125	150	9.375	4.253	46.29	102.14
5	7-32	.21875	5.55625	140	8.75	3.969	43.25	95.25
6	13-64	.203125	5.159375	130	8.125	3.686	40.15	88.50
7	3-16	.1875	4.7625	120	7.5	3.402	37.03	81.78
8	11-64	.171875	4.365625	110	6.875	3.119	33.98	74.88
9	5-32	.15625	3.96875	100	6.25	2.835	30.89	68.09
10	9-64	.140625	3.571875	90	5.625	2.552	27.77	61.18
11	1-8	.125	3.175	80	5.	2.268	24.70	54.45
12	7-64	.109375	2.778125	70	4.375	1.985	21.55	47.62
13	3-32	.09375	2.38125	60	3.75	1.701	18.52	40.89
14	5-64	.078125	1.984375	50	3.125	1.418	15.40	34.04
15	9-128	.0703125	1.7859375	45	2.8125	1.276	13.93	30.59
16	1-16	.0625	1.5875	40	2.5	1.134	12.37	27.22
17	9-160	.05625	1.42875	36	2.25	1.026	11.12	24.50
18	1-20	.05	1.27	32	2.	.9072	9.880	21.78
19	7-160	.04375	1.11125	28	1.75	.7938	8.645	19.06
20	3-80	.0375	.9525	24	1.50	.6804	7.419	16.36
21	11-320	.034375	.873125	22	1.375	.6237	6.792	14.98
22	1-32	.03125	.793125	20	1.25	.567	6.177	13.62
23	9-320	.028125	.714375	18	1.125	.5103	5.555	12.24
24	1-40	.025	.635	16	1.	.4536	4.94	10.89
25	7-320	.021875	.555625	14	.875	.3969	4.325	9.53
26	3-160	.01875	.47625	12	.75	.3402	3.703	8.18
27	11-640	.0171875	.4365625	11	.6875	.3119	3.398	7.49
28	1-64	.015625	.396875	10	.625	.2835	3.089	6 81
29	9-640	.0140625	.3571875	9	.5625	.2552	2.777	6.12
30	1-80	.0125	.3175	8	.5	.2268	2.47	5.46
31	7-640	.0109375	.2778125	7	.4375	.1985	2.155	4.76
32	13-1280	.01015625	.25796875	6½	.40625	.1843	2.003	4.42
33	3-320	.009375	.238125	6	.375	.1701	1.852	4.09
34	11-1280	.00859375	.21828125	5½	.34375	.1559	1.700	3.75
35	5-640	.0078125	.1984375	5	.3125	.1418	1.549	3.40
36	9-1280	.00703125	.17859375	4½	.28125	.1276	1.393	3.06
37	17-2560	.006640625	.168671875	4¼	.265625	.1205	1.317	2.90
38	1-160	.00625	.15875	4	.25	.1134	1.237	2.72

UNITED STATES IRON AND TIN PLATE MANUFACTURING COMPANY,
DEMMLER, PA., *Sept.* 9, 1892.

J. G. BATTELLE, ESQ., *President*, PIQUA, OHIO.

Dear Sir: Your favor of the 7th inst. I received yesterday at Association office. I have noted contents carefully. The copy of the gauges scale appears to me to be correct, and I would be much obliged to you if you would send me about six copies of the same.

Replying to your questions, before I talk about the advantages which I claim for this proposed scale, will say that of all gauges I would give preference to the French gauge, based on the metric system. (Although a German by birth, I am liberal enough to acknowledge that the French give us a good many things that are nice.) But as long as we divide our pounds into ounces, and our lineal measure into 16ths, 32ds, and 64ths of an inch, the millimetre gauge will not be of much convenience to us; nor does the division into thousandths of an inch afford us very superior facilities for a quick determination of the weight when we know the thickness, or *vice versa*. But inasmuch as a square foot of iron one inch thick weighs 640 ounces, and one ounce is equal to .640, one six-hundred-and-fortieth of an inch, I have endeavored to arrange the scale in such a manner that each gauge number represents a stated amount of ounces per square foot; each one ounce per square foot represents one six-hundred-and-fortieth inch in thickness; therefore, if we know the weight per square foot we know at the same time the thickness of the sheet in six-hundred-and-fortieths of an inch.

A micrometer gauge, in which the dial and threads were so arranged that each division indicated a six-hundred-and-fortieth, or twelve-hundred-and-eightieth of an inch, could be as easily constructed as one which gives the thousandths of an inch. Then, if we measure a piece of iron by this gauge and have ascertained the thickness, we ascertain the weight per square foot at the same time.

If this proposed gauge should be adopted, I believe the denomination per ounces would soon be used altogether, instead of the number. For instance, instead of calling for No. 28 ga. (which at present may mean sheets weighing .5 lb., or 8 oz. per square foot, or may mean .64 lb., or 10¼ oz. per square foot, just according to which of the various gauges you refer to), you would call for a 10-oz. plate, and then there could be no doubt about what gauge you wanted.

If this mode should become popular, we could also do away with those obsolete denominations for tin and terne plates, as IC, IX, IXXX, DC, DX, etc. IC would be 8-oz. plate, IX would be 10-oz. plate, DC 10-oz. plate, and DX 13-oz. plate, etc.

I also think that the galvanizers who now figure the weight of gauges in ounces would find it very easy to adopt this method, as also the manufacturers of sheet iron and tinware, and the workers in sheet iron and tin plate generally.

In regard to the difference between iron and steel, would say that the same is so little, that for practical purposes it could hardly be considered, at least not until we have made some very great improvements in our art of rolling iron and steel into sheets.

I hope that this information will be satisfactory to you, and if you have any more questions to ask, I will gladly answer them to the best of my ability. I remain,

Truly your friend,

W. C. CRONEMEYER.

The Secretary reported that, in order to secure prompt consideration of this subject, it had not been thought worth while to delay the appointment of a committee to advise upon this request until it could be originated from the Convention, but that a committee consisting of Prof. Thomas Egleston and Mr. S. S. Wheeler had been appointed by the President to consider the request and report to the Convention. This committee addressed a letter to Mr. Battelle, suggesting that the columns in the proposed gauge giving the metrical equivalence should be added (which were not contained in the first form of the gauge table submitted), and suggesting the advisability of making the action of the interested associations one which should in its form be international in character, even if thereby the adoption of a gauge might be deferred a little while.

The report of the Committee was accompanied by the reply of Mr. Battelle to the letter of the Chairman, in which he requests that the Society of Mechanical Engineers appoint a committee to meet committees already appointed by the associations in interest.

The report is as follows:

To the Council of the American Society of Mechanical Engineers:

Gentlemen: I received on Nov. 7th from Dr. Hutton, Secretary of your Society, the enclosed papers, which I beg to return.

On your appointment of Mr. Wheeler and myself, we went over the matter, and as we found material for criticism, I wrote to Mr. Battelle, with the result of receiving the enclosed letter.

Your Committee do not feel justified in bringing the matter in its present shape before the Society. We wrote to Mr. Battelle for some concessions, with a view of reporting both for and against the proposed gauge, the result of which was the letter of Mr. Battelle of Nov. 14th, in which he requests that the Society of Mechanical Engineers will appoint a committee to work with such committees as he suggests for the presentation of the matter before Congress. No appointment for conference with your committee has been made. As this last request is entirely without the province of the Committee, and as the Committee has not been able to confer with Mr. Battelle, and does not think the adoption of the gauge in its present condition is advisible, we return the papers and beg to be discharged from further consideration of the subject.

Yours respectfully,

Thos. Egleston,
Schuyler S. Wheeler.

The Secretary read letters from Mr. J. G. Battelle and others.

Mr. Oberlin Smith.—May I ask whether a few words on that gauge question are appropriate here, under the head of new business, or under the head of the report read?

The President.—Any motion you may be pleased to make, if seconded, will bring the matter up properly.

Mr. Oberlin Smith.—I do not know whether I am prepared to make a motion for another committee or a continuance of the existing committee. But it does seem to me that the Society ought to take up this matter of thickness gauges. The whole world is struggling with a most barbarous system of sheet-metal and wire gauges. Even our own American gauge is entirely illogical, and these iron and steel men in the West are struggling to have a new gauge of their own, and are trying to saddle it upon us through Congress. I have not seen the latest, but I suppose it is, like all the rest of them, entirely arbitrary. This has the old backwardness about it, commencing with the low numbers for the large thicknesses and the high numbers for the small thicknesses. That is the first illogical part. A rational gauge would naturally start with the lowest numbers for the thinnest metals. It has the old disadvantage of being arbitrary and running in arbitrary series, which they all have. There are a dozen or twenty of them now with which we are bothered continually, besides the old English gauge, and the Birmingham, and the Stubbs, and the New National English gauge, and Brown & Sharp's. Then tin plate is sold by IC, IX, and IIX, and forty other arbitrary names which do not mean anything. The whole matter could be simplified right through and a uniform gauge made, simply by using thousandths of an inch. Prof. Egleston has referred to the metric system, which, of course, has many advantages, but which we Americans cannot adopt now; and, of course, whatever gauge we Americans do adopt must be translated into the metric system in another column. But, so far as we are concerned, we must work in inches. The whole thing could be settled by simply making a gauge which is uniform for all materials, and simply giving each thickness its designating number of thousandths of an inch. Fifteen thousandths thick could be called No. 15; anything that is ten thousandths, No. 10; anything that is fifty thousandths, No. 50. That would be perfect simplicity, perfect logic. You would run in the order of thicknesses. You would accommodate yourself to all possible materials. It seems to me that some scheme of that kind ought to be carried out, and that this Society ought to lend its great influence to such an important subject some way or other, and frown down any such scheme as this, and do all it can to beat it.

Major M. P. Wood.—I move that this meeting recommend that all gauges be denominated by numbers running from a thousandth of an inch. I do not think there is any practical man here who does not appreciate the remarks just made, and it will not require any very extended remarks of mine or of anybody else to convince him thoroughly of the practicableness of the suggestion. If it is in order, I would make that motion.

Mr. Oberlin Smith.—Anybody who will look at this proposed table will see the absurdity of the thing. We have got to count the naughts in the thick numbers. There are seven of them. The first one is half an inch. It would be a good deal easier to say that five hundred thousandths should be No. 500. The next is sextuple, the next quintuple, and then a two-naught and a one-naught, and the fractions of inches run down here to $\frac{1}{12}\frac{3}{80}$ in one case, and in another to $\frac{1}{6}\frac{7}{20}$, and so forth down. When I got up to talk I intended to make a motion, but I got so interested in mentally swearing at this gauge that I forgot about it. I do not know what form the pending motion is going to come out in, but I hope it will help the gauge question in some way. It may be a good thing to put it in proper shape so that it can go out in a letter-ballot so as to see what the opinion of the members of the Society at large is on the subject; but before doing that it ought to be in some such shape that they can vote upon it. It may be necessary to appoint a new committee to attend to this affair, but it has seemed to me that the question ought to be taken up and this movement in Congress headed off by the protest of this and other societies, and some design substituted perhaps. Whether we shall do this by letter-ballot or in some other way can be discussed by the Society on the motion.

Mr. O. C. Woolson.—I want to express myself as greatly surprised that a subject so important as this wire-gauge and plate-gauge is to every mechanic and every business man who has to deal with the subject has not prompted every man in the room to get up simultaneously here and protest against the adoption of any gauges as standard without a full discussion by this Society. If there is any society in the land competent to discuss a question of this kind, and who ought to do it, it is the American Society of Mechanical Engineers; and I repeat that I am surprised that these gentlemen who have been puzzled and annoyed and put to expense by the system of gauges which we have to-day, do not promptly get up and protest. I hope the matter, before we get through

with this meeting, will bring out a full and liberal discussion which shall result in something tangible to the benefit of the country and of this Society in particular.

Major Wood read his written motion, as follows:

Moved, That the American Society of Mechanical Engineers hereby recommend to the other American engineering and artisans' associations of the United States of America that the standard gauge for the measurement of all wire, sheets, tinned, galvanized, coated, or plain, comprising all the trade denominations of whatever name or character, be revised, and that the thickness of these materials be denominated by thousandths of an inch, and the number of said gauge be the said number of thousandths of an inch so expressed.

Major Wood.—I simply give it as the voice of this meeting, and suggest that this meeting extends to the other associations of America an intimation of what their action is, and their desire to meet on that ground and formally adopt, as the boiler makers have adopted, almost, a standard thickness for their sheets.

The motion was seconded.

Mr. Woolson.—I would like to make an amendment to that—that a committee be appointed from this Society to report on the subject.

Mr. Wood.—I would accept the amendment.

Mr. Oberlin Smith.—I second the amendment.

Mr. W. A. Pearson.—If we are buying sheet or rod of any of the different materials, and we had a standard gauge raising in one-thousandth of an inch, No. 1 gauge being one-thousandth of an inch, and No. 20 being twenty-thousandths of an inch, and so on up, and you were to order plate or rod from No. 30, it could not be misunderstood. If the maker's gauge with which he tested the plate or rod was worn larger, all that would be necessary would be to test the gauge with the standard rule, which would settle all dispute at once.

Mr. Woolson.—My object was that possibly the committee could harmonize the metric system by a proper classification in tables, and thereby satisfy some gentlemen who regard the metric system of so much importance.

Mr. Oberlin Smith.—The question will still be, when we order a thickness by a number: What will they sell as that number? If these fellows get in their new gauge we will have a third one. We will have to be careful and state in every order exactly which gauge we work by, and then find out whether their gauges are in good order. I have found in buying sheet metals that they are almost always too thick, and I attribute it to the wearing of the

gauge notches. By the proposed system of making the gauges to agree with micrometers, we can always find out if they are right. There is no objection to using numbers. It is the conventional system through the world. Yielding that to the old conventional way of using numbers, the whole thing would agree perfectly. It would apply to all materials, all dimensions, up to any amount at all. Even if the boiler plate ran up to one inch and a half, the same thing would apply all the way through; although generally, of course, it would be for small measurements below one inch. Again, if anybody does want to go into it so fine as to have metal ten and a half thousandths thick, it would only be necessary to add another figure. Another thing that could be done so easily in ordering tin plate—for instance, all the dimensions can be mentioned: No. 15—that would be what we now call one-cross tin; 10, 14 would mean 10 inches wide and 14 inches long. Strips of copper and brass could be measured in the same way. Brass 8 inches wide, $\frac{20}{1000}$ thick, and 100 feet long, would be expressed by 20–8–100. Of course, there may be better methods. I simply recommend that because it is the simplest and most logical to my mind, and I know to a good many others. The practical action we can take now is to appoint this committee and draw up some reply to the people who sent this thing, and if they bring it before Congress, send somebody there, or send some official communication to Congress from the Society, to protest against it; we should certainly try to prevent such a bad gauge as this being used by national authority, even if we do not get a good one just yet.

Mr. Jesse M. Smith.—This matter has all been gone into quite thoroughly by scientific societies in this country, notably the American Institute of Electrical Engineers and the National Electric Light Association. Both of them have had elaborate reports from committees, and the decimal system in thousandths of an inch has been very highly recommended. But, unfortunately, the gauge recommended has not been very generally adopted in the trade. It is becoming more and more so every year. If our Society joins with the others—with the electrical engineers and all the other scientific societies interested in the subject—it seems to me that some good ought to be brought out of it; and if this committee is appointed it would seem well that they consult with other committees that have been appointed by the like societies.

Mr. Babcock.—I would say, in regard to the question of the French metrical measures and the English, that this system provides the easiest solution of the matter which it is possible to give. This being given in fractions of an inch, any one knowing the relation between an inch and a millimetre can at once determine for himself what the number is in the metrical measures, and needs not go to any table to find out. Having one number given he can easily determine the others. I see no necessity of a committee, excepting for the purpose of consulting with other bodies on the subject.

Mr. Jno. T. Hawkins.—I think the necessity for appointing a committee in this case is very evident from the fact that if this Society adopts the particular method proposed, it only adds to the confusion already existing. That is, it initiates still another new standard. The principal object of this movement is, I imagine, to establish a uniformity among all users of gauges and purchasers of sheet metals and wire; and unless a committee is appointed who can procure the co-operation of the present divers authorities, we will only make the matter worse, instead of improving it. So far as those countries in which the inch unit is used are concerned, the plan proposed is simplicity itself, and, if agreed upon to the exclusion of all the present methods in those countries only, it would be a great step in advance. The only trouble with, as objection to it, lies in its extension to countries using the metric system only. The recognition of the numbers by the decimal expression for their measure could not extend to any country in which the inch unit is not used, but it would be a great boon if universally adopted in countries in which the inch is a unit of measure. To be of any value now, however, it must displace some or all of the diverse standards now in use, and this can only be had, if at all, through a committee or convention.

The President.—The debate has got a little in advance of the motion. Mr. Woolson's amendment being put in form, it would make Major Wood's motion, as amended, read in this way:

Resolved, That this matter be referred to a special committee of three, to be appointed by the Chair, to consider and report their recommendations to the Society after conference with similar committees from engineering manufacturers or other organizations.

Will Major Wood accept that as an addition to his motion?

Major Wood.—I will accept it.

Mr. E. F. C. Davis.—It seems to me that the present condition

of affairs with regard to the metal gauge is very much like the screw-thread question a few years ago, when the Franklin Institute took the matter up, there not being any other society of this kind in existence at that time. The Franklin Institute adopted what they thought was a desirable system of threads. They recommended them to the world at large as the Franklin Institute standard. I do not know that they thought it necessary to have an act of Congress passed to make it compulsory to use that standard. The Sellers Company, in Philadelphia, were very much in accord with it, and assisted very greatly by their example in bringing it into general use, and I think that grew into general use by mutual consent, very largely upon the recommendation of the Franklin Institute. It seems to me if this Society were to agree upon this standard as being the most sensible standard for sheet metal thicknesses, if they were to adopt that as the standard of the American Society of Mechanical Engineers, and request every member of the Society to use that standard, the sheet makers would find it necessary to have such gauges. Pratt & Whitney would, of course, very soon have such gauges on the market which every boiler maker and every sheet manufacturer could easily get for a dollar or two, so that all that the members of this Society would have to do would be to order sheets to the Mechanical Engineers' gauge and they would get them. It would be such an improvement on the existing gauge that the thing would bring itself into general use by its own common sense and adaptability. I think that would be the best way to get that gauge adopted. I do not see any better way. Our previous committee found it impossible to get such a thing passed through Congress. I would like to amend that motion in some way to make it carry that point with it; after the committee have decided on the best gauge, to recommend that to be the gauge in use by the members of this Society.

Mr. Oberlin Smith.—Mr. Davis might have gone further and said that after the Franklin Institute had adopted that gauge and recommended it, a board of United States Government officers took it up; in the Navy, I believe. I do not think Congress had anything to do with it. The Navy did adopt it, and it has been known as the United States Standard ever since, which gave it great weight. The United States Standard counts for a good deal more than the Franklin Institute Standard. If it were adopted by the Army, or Navy, or both, it would not be necessary to have

Congress adopt it at all. I agree with some of the gentlemen here, that it is not the thing for this Society to adopt off-hand this proposed gauge or any other. It wants to be a matter of conference, and it wants to be agreed upon by all the chief national engineering societies, if not by other organizations. Whether this Society alone should adopt it if the others fail to do so is a question. If the others will not do anything about it, it will be time to talk about this Society adopting something as its own standard, and recommending its own members to use it. That alone would have great weight.

The President.—With regard to the matter of adoption of this standard by the Society, a vote was passed at a previous meeting that the Society would not *adopt* any standards or methods. So far as the Congressional action is concerned, it would probably go no further than that it should be used in Government work. There would be no effort to enforce it on outside manufacturers. As Mr. Smith says, the mere adoption of it by a bureau chief or the Secretary of the Navy would be a great point in its favor.

Mr. Holloway.—The Society has put itself on record that it is not advisable to adopt standards; and while this is no doubt a very excellent thing, I think there is no reason why this Society should depart from its former action in this respect. I think it very well that there should be a committee appointed, and that the committee should issue circulars and set forth the advantages that would accrue to everybody in the use of such a standard gauge, and the advantage that such a standard has over all other standards; and if they can induce other societies or associations to join with them it will add very greatly to the strength of the thing, and after that is accomplished they can recommend it, and the Society can recommend it. But I think it would be a mistake for the Society to adopt standards of any kind, because there are so many things wanting to be standardized that we would get into trouble.

The President.—The first motion is, that the American Society of Mechanical Engineers hereby recommend to the other mechanical engineering and artisan associations of the United States that the standard gauge for the measurement of all wire, sheets, tinned, galvanized, coated, or plain, comprising all the trade denominations of whatever name or character, be revised, and the thickness of their material be denominated by thousandths of an inch, and

the number of said gauge numbers be the said number of thousandths of an inch.

The second motion or resolution is, that the matter be referred to a special committee of three, to be appointed by the Chair, to consider and report their recommendations to the Society after conference with similar committees from other engineering or manufacturing organizations.

Considering these as one resolution, gentlemen, those who are in favor of this resolution will signify it by saying aye ; contrary minds, no. Carried.

At the close of the business before the meeting, the professional papers were taken up, the first being that by Mr. F. H. Daniels, entitled "An Interesting Boiler Explosion," which received very full discussion by Messrs. Stirling, McBride, Hawkins, Laforge, Nason, Le Van, Roelker, Holloway, Babcock, Platt, Denton, Woolson, Hunt, Manning, Oberlin Smith, Kafer, Hague, Winship, and Cartwright.

The morning session then adjourned to partake of a luncheon served in the Society's house in the commodious basement. The members present spoke in approving terms of this idea, which kept the company together for social and professional purposes, and made the afternoons an opportunity for enjoyable reunion. No definite assignment was made for the afternoons of Wednesday or Thursday, but the Local Committee had arranged for a number of points of interest which might be visited by the visiting members in small parties, which they might organize for their convenience.

The evening of Wednesday was devoted to a most successful reception of the members and their ladies to each other and their friends, held in the ball-room at Sherry's, 37th Street and Fifth Avenue. Over four hundred were present, and it was voted a brilliant affair.

THIRD SESSION.

The third session was convened on the morning of December 1st at 10 o'clock. The first paper, by Mr. Jas. B. Stanwood, entitled "Strains in the Rims of Fly-band Wheels produced by Centrifugal Force," received no discussion. That by Mr. F. M. Rites, entitled "An Analysis of the Shaft Governor," was discussed by Messrs. Ball, Carpenter, and Kerr.

That by Mr. W. A. Gabriel, on "A New Process for Cutting

Cams," and that of Mr. Geo. Richmond, "A Simple Difference Engine," received no discussion.

Mr. Geo. W. Bissell's paper, "The Strains in Lathe Beds," was discussed by Messrs. Oberlin Smith and W. S. Rogers.

"Tests of Driving Belts," by Mr. Samuel Webber, and the paper by Mr. W. F. Durand on the "Limit of Propeller Efficiency as Determined by Surface Form of the Propeller," received no discussion.

After the presentation by Mr. Geo. Richmond of his paper, "Notes on the Refrigeration Process, and its Proper Place in Thermodynamics," discussed by D. S. Jacobus, Mr. Holloway in a brief speech of introduction presented to the meeting Mr. Thomas F. Rowland, builder of the first Monitor, and for many years a life-member of this Society. The meeting received Mr. Rowland by rising, and upon his being escorted to the platform he spoke to his associates in a few feeling words of his recognition of the honor conferred.

Mr. Holloway's remarks follow.

Mr. Holloway.—May I beg your indulgence for a moment? When this Society was organized, among its first members was a gentleman who, during its early existence and up to the present time, has taken great interest in it; but who, unfortunately, owing to ill health, has not been able to be with us to any great extent, and is therefore comparatively a stranger in what now is a very large society, but what was at the beginning a very small one. This gentleman, I am very happy to say, is with us to-day. His interest in the Society, I am quite sure, is as great as that of any present; but for the reason I have mentioned—ill health—he has not been able to attend as many of our meetings as he would have liked, and as we certainly would have wished. He has been very intimately connected with some very important events in the history of our country, events which, when I name them, will recall to many here reminiscences of times and experiences which I am sure they will never forget; and they will be glad to know that that gentleman is with us to-day. But there has grown up and come into this great Society a large number of younger engineers who know of what is past mainly from history and from tradition, and I am quite sure that these younger engineers who are now coming on to the stage, and who soon will take the places of the early founders of this Society, will be also glad to know that the gentleman I refer to is here to-day, and will be

glad to see him. With this brief and imperfect presentation of the matter, I am going to ask you, gentlemen, to do our President a favor, to do me a favor, and to do yourselves credit, in doing what I am sure you will all do with great pleasure, and in which I am sure our representatives from the other side of Mason and Dixon's line will join most heartily. I ask you, gentlemen, all to rise in recognition of, and in honor and respect for, Thomas F. Rowland, the builder of the *Monitor*.

After luncheon, as on the preceding day, the members separated for various excursions, and assembled anew in the evening.

FOURTH SESSION. THURSDAY EVENING, DECEMBER 1ST, AT 8 P.M.

Prof. De Volson Wood read two papers, the one on "Hydraulic Reaction Motors," and the other on "Negative Specific Heat," the latter being discussed by Mr. Geo. Richmond.

The rest of the evening was taken up in abundant discussion of the topic presented by Mr. H. F. J. Porter, covering the subject, "Shall there be an Overhauling of the Right to Use the Title 'Engineer'?" This was discussed by Messrs. Thurston, Hawkins, Cooper, Hill, Le Van, Draper, Oberlin Smith, Durfee, Spaulding, Kent, Strong, Cartwright, Darling, Rogers, and Henning.

A collation was served at the close of this debate in the lower room.

FIFTH SESSION. FRIDAY MORNING, DECEMBER 2D, AT 10 O'CLOCK.

The papers of this session were as follows:

By Prof. D. S. Jacobus, "Experimental Determination of the Heat generated per Candle Power in Oil Lamps," discussed by Prof. Thurston.

By Mr. R. Van A. Norris, "Tests of a Pump receiving Suction Water under Pressure," discussed by Messrs. Faber du Faur, Parsons, Platt, Wheeler, and Henning.

By Prof. W. H. Bristol, entitled "A New Recording Pressure Gauge for Extremely Low Ranges of Pressure," discussed by Messrs. Norris, Jesse M. Smith, Hawkins, Ball, and Henning.

By Prof. R. C. Carpenter, on "Comparative Variation in Economy with Change of Load in Simple and Compound Engines," discussed by Messrs. Thurston, Hill, Jesse M. Smith, Kerr, and Rockwood.

By Mr. H. C. Spaulding, entitled "A Variable Speed Power Transmission," discussed by Messrs. Wood, Walworth, Oberlin Smith, Jesse M. Smith, Kerr, Lipe, Low, Bancroft, Binsse, and Green.

By Mr. Anthony Victorin, entitled "Performance of an Overhead Travelling Crane operated by a Single Electric Motor," discussed by Messrs. Bancroft, W. L. Clark, Spaulding, Oberlin Smith, Jesse M. Smith, and Holloway.

By Mr. John T. Hawkins, on "A New Graduating Steam Radiator," discussed by Messrs. Bancroft, Green, Jesse M. Smith, Platt, Walworth, Parsons, and Breckenridge.

By Prof. H. C. Peabody, entitled "Tests on the Triple Engine at the Massachusetts Institute of Technology," discussed by Messrs. Hall, Jacobus, Rockwood, and Thurston.

At the close of the regular series of papers, two remaining Topical Discussions which had been printed were read and discussed. The contribution by Professor Sweet was entitled, "Is the Weaving Shed Design the Best Form of Construction for a Machine Shop?" discussed by Messrs. Woodbury and Holloway.

The other was by Mr. W. S. Rogers, "To What Extent Can the Milling Machine Replace the Planer?" discussed by Messrs. Henning, Oberlin Smith, and Lipe.

There being no other business presented, and the hour assigned for adjournment being already passed, the session adjourned to meet in July, 1893, as the Mechanical Section of the Columbian Congress of Engineers, in Chicago, Ill.

As Appendices to this summary of the proceedings of the meeting are the Reports of Special Committees. One is from the committee appointed at the request of the Committee on Awards of the World's Columbian Commission, and the other is the Report of the Committee on Standard Flanges, with discussion. They are printed as separate papers.

DIII.

REPORT OF A COMMITTEE OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS TO CONSIDER AND REPORT METHODS FOR PHYSICAL AND MECHANICAL TESTS ON STEAM-ENGINES AND MACHINES AT THE WORLD'S COLUMBIAN EXPOSITION, 1893.*

HON. ECKLEY B. COXE, PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, No. 12 WEST 31ST ST., NEW YORK.

Sir: The undersigned Committee of the Society, appointed, in response to a request from the authorities of the Columbian Exposition, to consider the subject of mechanical and physical tests at such Exposition, respectfully reports as follows:

The recurrence from time to time of international expositions not only enables one nation to keep pace with the developments of another in the various departments of science and art, but also furnishes an opportunity for careful tests by experts of the relative merits of the various products, manufactures, machines, and methods developed under different conditions in various parts of the world, and to ascertain in detail the differences in structure, composition, or method which cause the differences in result. It follows that, thereafter, more definite, logical, and consistent efforts are made to utilize the best known devices, materials, and methods, and future developments are on a higher plane and result in greater benefit to all concerned. The larger number of tests undertaken would naturally relate to prime movers and apparatus employed in connection therewith; but such tests to be complete should include also investigations to check and perfect our knowledge of the principles involved and of the nature of the methods and materials employed. In a broader sense the investigations should be extended in every path, not heretofore examined thoroughly, which leads to, grows out of, perfects, or modifies any of the great laws, methods, materials, or machines which enable the engineer "to harness the powers of Nature and guide them to and fro at will."

It is only when we attempt to make a list of such a series of tests that the magnitude of such a work can be appreciated. The following is a partial statement of tests which it is desirable to undertake with reference principally to prime movers and natural products, materials and apparatus, used in connection therewith:

(1) Tests of the absolute calorific and practical value of different fuels, particularly those available in the United States; to be made with apparatus capable of modification in order to ascertain the forms best adapted for the several fuels.

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* Prepared by request of the Committee on Awards of the World's Columbian Commission.

An exhaustive series of experiments would occupy several years, but tests of typical fuels and apparatus will be practicable and indicate the proper direction of further investigation.

(2) Tests of different types of steam boilers, classified as to size and the purposes for which they are to be employed. The collection of boilers of different kinds exhibited will furnish unequalled facilities for such trials.

(3) Tests of steam-engines, which should be classified as to type, size, and adaptability for particular purposes. This work is in itself of sufficient importance to occupy the attention of several observers throughout the entire Exposition.

(4) Tests of different kinds of pumping machinery, classified first as to the source of power, for instance, as operated by steam or other prime movers, with sub-classification suited to different degrees of economy and adaptations for various purposes. In this connection valuable tests can also be made of the simpler forms of power and hand pumps.

(5) Tests of attachments to boilers, engines, and pumps, such as safety valves, safety attachments, feeding devices, the various kinds of regulators, and other details of the kind.

(6) Tests of heat-engines other than steam-engines ; for instance, those in which the transmitting medium is air, the lighter products of petroleum, aqua ammonia, or other fluid.

(7) Tests of turbines and other water motors. Such tests when properly discussed in connection with accurate plans of the several devices would be of the highest scientific and commercial value.

(8) Tests of windmills of various kinds and sizes.

(9) Tests of means of transmission, designed to show the improvements that have been made in gearing, belting, etc.

(10) Tests of steam-locomotives, designed particularly to show the improvements that have been made in increasing the power of modern locomotives, and the effect and influence of higher steam-pressures, compounding, etc.

(11) Tests of apparatus relative to railroads, such as details of construction of locomotives and cars, air brakes, signalling apparatus, etc.

(12) Tests of improvements in marine propulsion, including improved details of propelling machinery, the comparative efficiencies of different forms of water-wheels and propellers, the value of various safety devices, of apparatus for handling merchandise, of steam-steering devices and the like. Necessarily, tests of this kind must be confined to competitive structures and devices actually on exhibition.

(13) Tests of fire-engines, directed particularly to ascertain the relative efficiency, compared to weight, of portable engines, with other trials to determine the question of reliability under the conditions of practical use.

(14) Tests of electrical apparatus which involve the transmission of motion, such as complete trials of the electrical and practical efficiencies of dynamos and electric motors under various applications ; tests of electrical locomotives and of various details relative to electrical haulage.

(15) Tests of competitive details of cable railways and miscellaneous means of propulsion.

(16) Tests of the strength and physical characteristics of new materials and of new shapes and combinations of materials that may be brought out during the Exposition.

A series of experiments of the highest value can be made by forming com-

pounds of given metals, progressively varying the proportions and testing their physical properties.

The members of the Committee have discussed the scope of the proposed experiments in accordance with two general methods, the second in a sense being an elaboration of the first, viz.:

(1) The exercise only of such care and elaboration in the nature and number of observations as to show indisputably the relative performance of different machines, so that a manufacturer may claim a commercial superiority for his device, based on the result of reliable tests under competent authority; and to record, in connection with such trials, the governing dimensions of the different machines, and the data customarily taken under such circumstances, such, for instance, when testing a steam-engine, as the power, the distribution of the steam, the quantity of fuel consumed, the weight of water evaporated, the quality of the steam, the steam-pressures and vacuum and the various temperatures, together with, in important cases, the chemical composition of the coal and of the escaping gases.

(2) To ascertain, in addition to the above, such particulars as are necessary to distinguish how the performance of each machine corresponds with or differs from the accepted theories on the subject; and to so formulate the results that the theories themselves may be enlarged or otherwise modified, and additions be made on a scientific basis to the strictly theoretical knowledge of the subject.

The difference between the two methods may be so far widened that neither will be satisfactory, for the experimental observations may on the one hand be so limited that little will be known except which device performed best during a particular trial under conditions not fully recorded, somewhat on the basis of a horse-race, and, on the other hand, the elaboration of details may be carried to such a great extent that comparatively little will be accomplished in the endeavor to do everything superlatively well.

The Committee has endeavored to formulate a course of action which will accomplish the desired end under conditions adapted to each particular case, and suggest such an organization that the relative merits of different methods may be continually considered and reconsidered, and results secured as complete, both as respects number and quality, as is possible with the means available.

An examination of the general statement of desirable tests, given above, will show that the less important devices may be tested in the simplest way, as all the principles involved can be studied more satisfactorily and with greater accuracy during experiments with larger apparatus of the same kind.

While we understand that by direction of the Department of Awards the reports of the judges are to be on a non-competitive basis, as between the different exhibitors, the experience in similar cases has been that at times the judges of particular groups desire tests to be made to ascertain if devices are even entitled to notice. Under non-competitive conditions, however, the greater part of the tests will be made to increase the general fund of information as to methods, mechanism, and materials. Some of the tests will be desired by the exhibitors themselves, to show the relative performances of different machinery by different makers on an assumed practical basis satisfactory to them, but not sufficient in all cases to differentiate the results due to design, good workmanship, or skilled inspection, from those arising from good management or even accident at the time. Many such experiments can, by simply increasing the number of observers, furnish considerable data of value on a scientific basis. All tests of this kind will be at the expense of the exhibitors, and they can also be persuaded in

some cases to contribute to more elaborate experiments with typical apparatus of a given kind, designed to establish standard methods of construction and to furnish information in regard to the principles involved. It will be well to merely publish the results of such experiments, stating that they were made with certain machines of certain sizes and peculiarities of construction, operated under the conditions stated, and giving results in detail; stating also in general terms the lessons to be learned and the modifications that are desirable in future constructions, but without mentioning the names of manufacturers of competing articles or otherwise distinguishing them.

Some of the more important apparatus exhibited should be tested as thoroughly in every respect as is possible. For instance, in making experiments with a large pumping engine it will be practicable to employ a sufficient number of observers to ascertain in the fire-room the amount of coal consumed and the quarter-hourly rate of combustion, the hygroscopic condition of the coal, the analysis of the same and of the products of combustion, the water evaporated, the various temperatures of the water, steam, and up-take, also of the boiler walls and boiler and pipe coverings; in the engine-room, to indicate at frequent intervals the various steam cylinders and pumps, observing the various pressures and temperatures, including the variations in pressure and temperature as the steam passes from one cylinder to the next, and the temperature of the metal of the cylinder at different points and at different depths from the surface; to weigh the condensed steam from the jackets and intermediate chambers, measure the condensing water and its range of temperature; to ascertain the quantity of water which should be displaced by the pump capacity and that delivered by actual measurement; to ascertain the head and check the same by actual measurement, and to trace out the various losses of pressure in the suction and discharge mains and in the pump and its valves. Finally, from these and more delicate observations, the total amount of potential energy stored up in a given fuel may be compared with the various transmutations, transfers, and losses incident to the cycle of operations—a detailed statement made of each utilization and loss with its location and value, all carried out so carefully that the thermal units finally unaccounted for will be but a trifling percentage of the whole. In a similar way the indicated power of the engine can be compared with that absolutely available from the energy of the heat force, and in detail with that utilized in lifting the water and lost in friction at different points about the engine and in the pumps and mains, so that the number of foot-pounds unaccounted for will be reduced to a very small percentage of the whole. Such experiments will naturally be repeated at different pressures with different conditions of the steam as respects superheating; also with and without steam jackets, and with various degrees of compounding, and cover all possible changes which will be of value in relation to the particular subject under investigation.

It is believed, if all the refinements known to modern science be adopted in a few important experiments, that what may be called more practical trials will be sufficient to attempt in the majority of cases, and in this way very much work be accomplished and the demands of scientific and commercial advocates be reasonably acceded to.

With these considerations as to the general nature of the results which may be attempted, we pass to the consideration of an organization to conduct the work and an estimate of its probable cost.

It is recommended that the experiments be put in general charge of a commission of experts, including among its members those of the necessary scientific,

practical, and business qualifications to insure that important portions of the work done may be analyzed in the most thorough and scientific manner; that a sufficient number of experiments be made in all departments to satisfy all practical demands when considered either in an engineering or commercial sense; that the whole business be conducted with such regard to business principles as to insure that no work will be attempted which cannot be completed with the time and means available; that all work be carried forward in a prompt and business-like way, reported upon and finally completed at the proper time, and that the organization in detail be such that all these results may be obtained without clashing of authority or disputations as to the accuracy of the results. It is believed that a commission of engineers may be selected competent to accomplish this purpose, and it is recommended that such commission be organized as a subsidiary bureau under some department of the Exposition, through which it will report, and that all tests, except those herein excepted, be referred to and conducted under the direction of such Bureau of Tests.

The work of the Bureau of Tests would be of such nature that it will naturally be initiated by the Department of Awards, but it will be necessary to prepare for and to conduct the tests in the Department of Machinery. It may therefore be desirable that the formal reports of such a bureau be made through the Department of Machinery to the Department of Awards, so that both departments will be directly interested in furthering the work. Some such organization is absolutely necessary to insure confidence and even to prevent difficulty. Without it, if a group of judges wish to make a few tests of products or mechanism, merely to satisfy their minds in regard to particular points, they must needs call upon the Department of Machinery for space, apparatus, and necessary assistance, and sooner or later in attempting to work independently will clash with some of the regular work under the proper bureau, or, by attempting to conduct experiments themselves when other duties press, accomplish their work in an unsatisfactory and perhaps in a very expensive way; whereas if in such cases the Chairman of the Group of Judges, through the Department of Awards, addressed the Chief of the Bureau of Tests through the routine established, stating in detail exactly what is desired, the proper facilities and apparatus and the necessary assistance can in general be provided so that the work will be conducted in an efficient and economical way, satisfactory to all parties concerned. Such work may even be done by the judges themselves or under their supervision if initiated and reported through the Bureau of Tests.

It is recommended that at first the number of members of the Bureau of Tests be kept as small as possible, and as the nature of the work which it is possible to undertake with the co-operation of the exhibitors develops, other experts in special branches of science may be added so that the work of the bureau may be done under the advice of an expert member, but without departing from the unity of a strong, distinct organization. If, however, experiments of a comparatively trifling nature are required in certain branches, it may be desirable to simply employ an expert to recommend in detail a certain series of tests, superintend the same, and report directly to the bureau. If a series of important experiments with electrical apparatus are desired, one of recognized authority on electrical matters should be added to the membership of the Bureau of Tests. If, however, as suggested in the general list above, the electrical investigations be confined to tests of electrical apparatus which involve the "transmission of motion," which language is intended to exclude laboratory and telegraphic experiments, it may be that the tests of dynamos and motors and the various features

of electrical propulsion can be conducted for the bureau under the direction of an expert employed for the purpose.

The bureau should be organized with a Chief or Chairman, corresponding with similar officers of the other bureaus of the Exposition, and the members should select from their own number a Vice-Chairman and Secretary.

The bureau should be authorized to appoint an expert as Superintendent and another as Assistant Superintendent, and such other expert assistants and observers as may be necessary. The Superintendent should have executive charge of all the work of the bureau, and the same be conducted in accordance with regulations issued or approved by the bureau.

It is recommended that at first the members of the Bureau of Tests have simply honorary positions, with provision for payment of expenses during meetings, but that they be authorized to appoint a Superintendent at an early date who will represent them in preparing for experimental work at the Exposition grounds while the machinery is being installed, and in consultation with them and with the Exposition authorites make such arrangements as are necessary in advance. The Superintendent can also, by conference or correspondence with exhibitors, develop at an early date an interest in the proposed work of the bureau.

It is not thought that an important work of this kind can be accomplished without expense to the Exhibition authorities. It cannot, however, be properly charged to the regular work of any particular department. It is in a sense an independent work, which, however, should be encouraged by and reported through existing departments in an orderly way. The expenses of some of the tests may be borne by voluntary subscription, but the organization, to be efficient, cannot be maintained that way. Necessary testing machines and instruments, with trifling exceptions, will be gladly loaned by the manufacturers, but some portable apparatus will need to be constructed for the particular location.

It is believed that the sum of $50,000 can be advantageously expended throughout the Exposition in making tests of the kind indicated, but it will only be necessary to provide at first for the salary and office expenses of the Superintendent and travelling expenses of the members of the bureau. Suitable space should, however, be set aside for a small laboratory in which tests can be made which cannot be conducted with machines in place in the Exposition, and which will serve also as headquarters and space for the adjustment and storage of special apparatus. It is believed that 1,500 to 2,000 square feet of floor surface will eventually be required for this purpose. Some reasonable expenses will be involved also for putting apparatus in place for the special use of the bureau.

The bureau should have power to arrange for contributions from exhibitors and a moderate appropriation to draw upon to make up deficiencies; but it will be entirely practicable, when a very expensive series of tests are contemplated, to report the facts to the general authorities of the Exposition and request an appropriation at the time for the particular purpose.

The following are some of the recommendations which may be here referred to as desirable for such a bureau to observe:

(1) Exhibitors should be required to furnish complete plans in detail of every part of the apparatus which it is proposed to test, so that the results may be traced back to the differences in construction or mechanism, and clearly pointed out in the reports.

(2) The instruments employed should be of such size and construction that they may be observed by experts appointed by the exhibitors themselves, and thereby complete knowledge be obtained by every one interested, as the experi-

ments progress; and rules should be promulgated, that exhibitors and others interested should through their own experts make any and all protests as to the accuracy of any readings or the inefficiency of any methods at once, while the experiments are in progress, so that investigations may be made at the time, necessary corrections and repetitions made, and all preliminary questions settled at once.

(3) All the work which it is expected will have any scientific value should be conducted in accordance with standard methods approved by the American Society of Mechanical Engineers and other engineering societies here and abroad, and the results be reported in form and terms to correspond so far as practicable with the reports of standard tests which have been made in different parts of the world. If for any reason novel and special features are introduced in making experiments they should be clearly separable from the observations made according to standard methods; and a summary of the general nature of the results should in all cases be provided in a prominent position in the report, for the inspection of those to whom the refinements of more elaborate methods will have no special interest.

The proposed method of organization makes it unnecessary to specify the methods of conducting experiments in detail, and it is believed that if such an organization be inaugurated it will not only obviate the necessity of hastily arranged tests provided with ill-considered and insufficient equipment, but enable the more important exhibits to be tested as thoroughly as can be desired, and very rapid progress to be made with tests of less importance, without any sacrifice of accuracy as to principal particulars in regard to which the majority of parties wish to be informed.

Respectfully submitted.

(Signed) CHAS. E. EMERY.
R. H. THURSTON.
WM. KENT.

No. 12 W. 31st St.,
NEW YORK, *December* 1, 1892.

DIV.*

REPORT OF THE COMMITTEE ON FLANGE STANDARDIZATION.

NEW YORK, *November* 30, 1892.

TO THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Gentlemen: It will be recollected that at the last meeting, when a report of progress was made, it was stated that blanks for the purpose of eliciting information as to just what sizes were in use had been sent out, and that, although a considerable number of replies had been received, additional data would be of value, and therefore more time was asked.

Some further information was elicited, and we now hand you, accompanying this report, tables showing details from about twenty-five manufacturers, giving as full particulars as are apparently obtainable.

The large diversity of dimensions is due doubtless to the individual growth of each concern, which has from time to time made only what its own requirements and experience indicated to be desirable; and with these divergencies to face it is evident that the problem of standardization presents some difficulties.

While the dimensions given by manufacturers of cast-iron pipe are comparatively small, the gates and valves which are to be used in connection with them are universally considerably heavier, which suggests the inquiry—why the slight additional thicknesses necessary may not be made by pipe manufacturers. The cost of moulding would be the same, and the only apparent increase in cost of product would be the very few pounds of additional metal necessary, and a trifling addition to the expense of facing; for in the latter case most of the time expended is in adjusting and centring work in the lathes.

Another difficulty met with was to harmonize the measurements of flanges used in conjunction with wrought-iron pipe with those of gates and water mains. They have been generally made larger than cast-iron pipe sizes, owing, first, to a reënforcing fillet encircling the pipe above the flange, and, second, to an increased diameter due to the necessity for a reasonable width of gasket outside of the inner flange face where the metal is cut out for wrought-iron pipe insertion.

If after further consultation with manufacturers it appears that they would be willing to increase slightly the dimensions of most of the flanges now made, the difficulty caused by the fillet can be avoided by making all flanges at their inner faces, except the smallest sizes, of sufficient thickness to insure the proper depth of pipe thread. For lower pressures, where a lesser thickness of metal will serve, a reduction may be made on the general surface, leaving the centre around the pipe of the standard thickness—bosses for the bolts being kept at the same level as that of the inner flange face.

If this method of construction is adopted it would appear to have the conspicuous

* Presented at the New York Meeting of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

advantage of reducing both the measurements of the bolt circles and the flanges, for the distance between the nuts and outside of the wrought-iron pipe surface may evidently be reduced by the thickness of the reënforcement formerly used, with the fillet at its base.

Before proceeding further with their work or communicating with manufacturers, your Committee would seek aid and counsel from the members of the Society, and would particularly ask that, after an examination of the table herewith submitted,

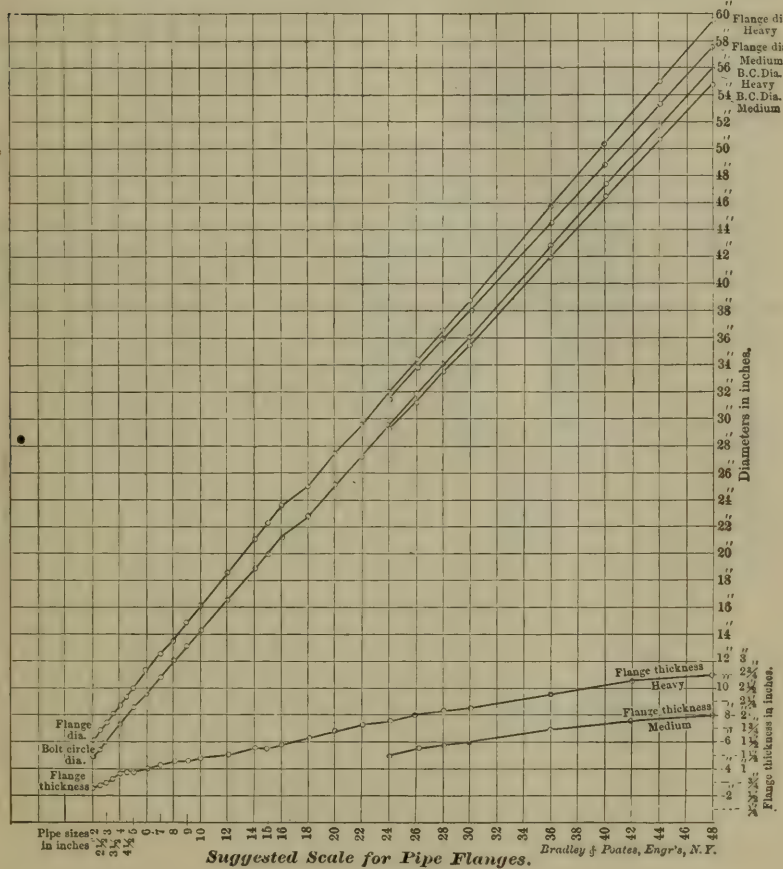

FIG. 186.

they write as early as convenient, offering any criticisms or suggestions that may occur to them.

In addition to the table of standards proposed, tables of sizes in use by manufacturers are also submitted, together with a plotted diagram (Fig. 186) showing graphically the form the scale under consideration takes on cross-section paper.

Scales for two pressures are proposed for sizes of 24 inches and over, as it was evident that from this size out the discrepancy in measurements, both in pipe thickness and flanges, begins to be so great that two standards would seem

advisable : one for pressures ranging up to eighty pounds and the other to two hundred.

The lighter scale might perhaps be carried below 24-inch, but the objection to so doing is that at this point the difference in sizes is not very large ; and, as many of the builders of pumping engines use considerable quantities of pipe ranging from 18-inch to 24-inch, a small difference in the dimensions of the two scales might lead to confusion.

While the dimensions submitted on the suggested table would seem to your Committee to represent a mean which, while sufficiently large to meet the stress there may be put upon them, would not be unduly heavy, and the change from the manufacturers' present standards to the new one would not be a great imposition of expense or annoyance to them when compared with the advantages to be derived from a Common Standard.

This scale is submitted only for criticism, and it is hoped that discussion on the subject may be general at the meeting, where the views of members can be exchanged more freely than is practicable by long correspondence.

To those who may object to the slight increase of thicknesses proposed, it may be asked whether the time and money saved by the facility which a Common Standard affords for the prompt assembling of parts, and also the certainty of stopping leaks by having metal enough where, previously, a flange has been only just heavy enough, without any factor of safety, would not justify the slightly increased cost?

Respectfully yours,

Committee on Flange Standardization.

CARLETON W. NASON, *Chairman.*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—NEW YORK MEETING, NOVEMBER 29 TO DECEMBER 2, 1892: FLANGE STANDARDS—SUBMITTED FOR DISCUSSION.

Pipe size, inches.	Pipe thickness, $\frac{P + 100}{4\,S}\,d + .333\left(1 - \frac{d}{100}\right)$	Thickness, nearest fraction, inches.	Stress on pipe per square inch @ 200 lbs.	Radius of fillet, inches.	Flange diameters, inches.	Flange thickness, inches.	Width flange face, inches.	Bolt circle diameter, inches.	Number of bolts.	Bolt size diameters, inches.	Bolt length, inches.	Stress on each bolt, per square inch, at bottom of thread @ 2.0 lbs.
2	.409	$\frac{7}{16}$	460	$\frac{1}{4}$	6	$\frac{7}{16}$	2	$4\frac{3}{4}$	4	$\frac{3}{4}$ $\frac{5}{8}$	2	825
$2\frac{1}{2}$	.429	$\frac{7}{16}$	550	$\frac{1}{4}$	$6\frac{1}{2}$	$\frac{7}{16}$	$2\frac{1}{4}$	$5\frac{1}{2}$	4	$\frac{3}{4}$ $\frac{5}{8}$	$2\frac{1}{2}$	1050
3	.448	$\frac{7}{16}$	690	$\frac{5}{16}$	$7\frac{1}{2}$	$\frac{7}{16}$	$2\frac{1}{4}$	6	4	$\frac{3}{4}$ $\frac{5}{8}$	$2\frac{1}{2}$	1330
$3\frac{1}{2}$	.466	$\frac{1}{2}$	700	$\frac{1}{4}$	8	$\frac{7}{16}$	$2\frac{1}{4}$	$6\frac{1}{2}$	4	$\frac{3}{4}$ $\frac{5}{8}$	$2\frac{1}{2}$	2530
4	.486	$\frac{1}{2}$	800	$\frac{5}{16}$	$8\frac{1}{2}$	$\frac{7}{16}$	$2\frac{1}{2}$	$7\frac{1}{2}$	4	$\frac{3}{4}$ $\frac{5}{8}$	$2\frac{1}{2}$	2100
$4\frac{1}{2}$	.498	$\frac{1}{2}$	900	$\frac{5}{16}$	$9\frac{1}{2}$	$\frac{7}{16}$	$2\frac{1}{2}$	$7\frac{1}{2}$	8	$\frac{3}{4}$ $\frac{5}{8}$	3	1430
5	.525	$\frac{1}{2}$	1000	$\frac{5}{16}$	10	$\frac{7}{16}$	$2\frac{1}{2}$	$8\frac{1}{2}$	8	$\frac{3}{4}$ $\frac{5}{8}$	3	1630
6	.563	$\frac{9}{16}$	1060	$\frac{1}{4}$	$11\frac{1}{2}$	1	$2\frac{5}{8}$	$9\frac{1}{2}$	8	$\frac{3}{4}$ $\frac{5}{8}$	3	2360
7	.60	$\frac{5}{8}$	1120	$\frac{1}{4}$	$12\frac{1}{2}$	$1\frac{1}{16}$	$2\frac{5}{8}$	$10\frac{1}{4}$	8	$\frac{3}{4}$ $\frac{5}{8}$	$3\frac{1}{2}$	3200
8	.639	$\frac{5}{8}$	1280	$\frac{1}{4}$	$13\frac{1}{2}$	$1\frac{1}{4}$	$2\frac{3}{4}$	$11\frac{1}{4}$	8	$\frac{3}{4}$ $\frac{5}{8}$	$3\frac{1}{2}$	4190
9	.678	$\frac{11}{16}$	1310	$\frac{5}{16}$	$14\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{7}{8}$	13	12	$\frac{3}{4}$ $\frac{5}{8}$	$3\frac{1}{2}$	3610
10	.713	$\frac{3}{4}$	1330	$\frac{5}{16}$	16	$1\frac{3}{16}$	3	$14\frac{1}{2}$	12	$\frac{3}{4}$ $\frac{5}{8}$	$3\frac{1}{2}$	2970
12	.79	$\frac{13}{16}$	1470	$\frac{5}{16}$	$18\frac{1}{2}$	$1\frac{1}{4}$	$3\frac{1}{4}$	$16\frac{1}{2}$	12	$\frac{7}{8}$ $\frac{3}{4}$	$3\frac{1}{2}$	4280
14	.864	$\frac{7}{8}$	1600	$\frac{5}{16}$	21	$1\frac{5}{16}$	$3\frac{1}{2}$	$18\frac{3}{4}$	12	$\frac{7}{8}$ 1	$4\frac{1}{2}$	4280
15	.904	$\frac{15}{16}$	1600	$\frac{5}{16}$	$22\frac{1}{2}$	$1\frac{5}{16}$	$3\frac{5}{8}$	20	16	$\frac{7}{8}$ 1	$4\frac{1}{2}$	3660
16	.946	1	1600	$\frac{5}{16}$	$23\frac{1}{2}$	$1\frac{7}{16}$	$3\frac{3}{4}$	$21\frac{1}{4}$	16	$\frac{7}{8}$ 1	$4\frac{1}{2}$	4210
18	1.02	$1\frac{1}{16}$	1690	$\frac{5}{16}$	25	$1\frac{9}{16}$	$3\frac{7}{8}$	$22\frac{3}{4}$	16	1 $1\frac{1}{8}$	$4\frac{1}{2}$	4540
20	1.09	$1\frac{1}{8}$	1780	$\frac{5}{16}$	$27\frac{1}{2}$	$1\frac{11}{16}$	$3\frac{7}{8}$	25	20	1 $1\frac{1}{8}$	5	4490
22	1.18	$1\frac{3}{16}$	1850	$\frac{1}{4}$	$29\frac{1}{2}$	$1\frac{13}{16}$	$3\frac{7}{8}$	$27\frac{1}{4}$	20	1 $1\frac{1}{4}$	$5\frac{1}{2}$	4320
24	1.25	$1\frac{1}{4}$	1920	$\frac{1}{4}$	$31\frac{1}{2}$ 32	$1\frac{1}{4}$ $1\frac{1}{4}$	$3\frac{3}{4}$ 4	$29\frac{1}{2}$ $29\frac{1}{2}$	20	1 $1\frac{1}{4}$	$5\frac{1}{2}$	5130
26	1.30	$1\frac{5}{16}$	1980	$\frac{1}{4}$	$33\frac{1}{2}$ $34\frac{1}{2}$	$1\frac{3}{8}$ 2	$3\frac{7}{8}$ $4\frac{1}{2}$	$31\frac{1}{2}$ $31\frac{1}{2}$	24	1 $1\frac{1}{4}$	$5\frac{1}{2}$	5030
28	1.38	$1\frac{3}{8}$	2040	$\frac{1}{4}$	36 $36\frac{1}{2}$	$1\frac{15}{16}$ $2\frac{1}{16}$	4 $4\frac{1}{2}$	$33\frac{1}{2}$ 34	28	1 $1\frac{1}{2}$	6	5000
30	1.48	$1\frac{1}{2}$	2000	$\frac{1}{4}$	38 $38\frac{1}{2}$	$1\frac{1}{2}$ $2\frac{1}{4}$	4 $4\frac{5}{8}$	$35\frac{1}{2}$ 36	28	$1\frac{1}{4}$ $1\frac{3}{8}$	$6\frac{1}{2}$	4590
36	1.71	$1\frac{5}{8}$	1920	$\frac{1}{4}$	$44\frac{1}{2}$ $45\frac{1}{2}$	$1\frac{1}{4}$ $2\frac{3}{8}$	$4\frac{1}{4}$ $4\frac{1}{2}$	42 $42\frac{1}{4}$	32	$1\frac{1}{2}$ $1\frac{3}{8}$	$6\frac{1}{2}$	5790
42	1.87	2	2100	$\frac{1}{4}$	51 $52\frac{1}{2}$	$1\frac{7}{8}$ $2\frac{5}{8}$	$4\frac{1}{2}$ $5\frac{3}{8}$	$48\frac{1}{2}$ $49\frac{1}{2}$	36	$1\frac{1}{2}$ $1\frac{1}{2}$	$7\frac{1}{2}$	5700
48	2.17	$2\frac{1}{4}$	2130	$\frac{1}{4}$	$57\frac{1}{2}$ $59\frac{1}{2}$	2 $2\frac{3}{4}$	$4\frac{3}{4}$ $5\frac{1}{4}$	$54\frac{1}{2}$ 56	44	$1\frac{5}{8}$ $1\frac{1}{2}$	$7\frac{1}{2}$	6090

NOTES.— Sizes up to 24 inches are designed for 200 lbs. or less.

Sizes from 24 to 48 inches are divided into two scales, one for 200 lbs. the other for less.

The two sizes of bolts given are for medium and high pressures.

The sudden increase in diameters at 16 inches is due to the possible insertion of wrought-iron pipe, making with a nearly constant width of gasket a greater diameter desirable.

When wrought-iron pipe is used, if thinner flanges than those given are sufficient, it is proposed that bosses be used to bring the nuts up to the standard lengths. This avoids the use of a reënforcement around the pipe.

Figures in the third, fourth, fifth, and last columns refer only to pipe for 200 lbs. pressure.

Respectfully submitted,

Committee on Flange Standardization.

DV.

PRESIDENT'S ANNUAL ADDRESS.

THE STEAM-ENGINE IN MODERN CIVILIZATION.

"Then everything includes itself in Power."

BY CHARLES H. LORING, BROOKLYN, N. Y.

(President of the Society, 1891-92.)

THE great historian who looks back a century nence upon the present era, with its numerous ramifications condensed by time into one focus, wherein the smallness of the field and the intensity of the light enables him to see plainly what we now only dimly discern, will point out that the great underlying cause of the wonderful progress made by mankind during the last hundred years was the steam-engine.

And why should this particular machine have produced such amazing results?

Many other machines which preceded and accompanied its development are quite as ingenious mechanical combinations and involved quite as much knowledge and skill in their conception and construction as the steam-engine, but the effects of which were, comparatively, both local and trivial, producing scarcely a ripple on the current of human affairs. Had they never been, the world would have lost but little.

The answer is that the steam-engine, with all its simplicity, is, what no other machine ever was, the creator of physical power, and this to so enormous an extent, at so small a cost, in so portable a form, and with such convenience of application, that it speedily revolutionized the economy of labor, and in so doing necessarily revolutionized all the conditions of man; for they all have been dominated by the labor question—the great bread-and-butter problem—since the primal curse was branded on the brow of the first man. It was to the relief of all mankind, in the struggle to find what to eat and wherewithal to be clad, that the immortal inventor of the steam-engine gave to the world the finest solution of the problem it can ever hope to receive.

He builded wiser than he knew.

He retired contented with the profits of his invention, and died without dreaming that he had placed on earth an infant Hercules whose club, with an ever-increasing might, would batter down the institutions of preceding ages; whose right arm, endowed with an ever-increasing power, would erect those of succeeding ages on foundations as different as strength differs from weakness, making possible the wonderful development of the man of the past into the man of the present.

All that man has, he has obtained from the earth, and is the direct product of physical labor, and the sum of his possessions is directly as the quantity of this labor expended. So long as this was manual labor, his possibilities were limited by the number of men available.

Here was the barrier that confronted the man of the past, and until the advent of the steam-engine progress was necessarily difficult and slow; and the little which was made in the centuries during which he had plodded upon earth was local, confined to few localities, and at the expense of progress elsewhere.

The civilizations of antiquity were limited to a few cities, and were based upon slave labor, the slaves being drained from other places, which were thus doomed to deepening barbarism.

The limit of possible slavery was the limit of the ancient civilization. When the maximum number of slaves who could be advantageously supported on any particular territory was reached, civilization stopped, except where direct robbery of other territory enabled it to maintain a fatuous existence; and the limit here was soon reached, for this was a system of "killing the goose that laid the golden egg."

The disgrace of the ancient civilization was its utter want of humanity. Justice, benevolence, and mercy held but little sway; force, fraud, and cruelty supplanted them. Nor could anything better be expected of an organization based on the worst system of slavery that ever shocked the sensibilities of man. As long as human slavery was the origin and support of civilization, the latter had to be brutal, for the stream could not rise higher than its source. Such a civilization, after a rapid culmination, had to decay, and history, though vague, shows its lapse into a barbarism as dark as that from which it had emerged.

Modern civilization also has at its base a toiling slave, but

one differing widely from his predecessor of the Ancients. He is without nerves, and he does not know fatigue. There is no intermission in his work, and he performs in a small compass more than the labor of nations of human slaves. He is not only vastly stronger, but vastly cheaper than they. He works interminably, and he works at everything; from the finest to the coarsest, he is equally applicable. He produces all things in such abundance, that man, relieved from the greater part of his servile toil, realizes for the first time his title of Lord of Creation. The products of all the great arts of our civilization, the use of cheap and rapid transportation on land and water, and of printing, density of population everywhere, the instruments of peace and war, the acquisition of knowledge of all kinds, are made the possibility and the possession of all by the labor of this obedient slave which we call steam-engine. He is no product of nature, but purely the creation of art alone. He works for all alike, and he works forever. His labor fills the earth, and makes manifest the latent virtues and intelligence of our race. The immense ameliorations of modern society are due to the same cause; and so great is the beneficence, that, without irreverence, the steam-engine may be truly called the material saviour of man.

We who were born under this benign influence but vaguely appreciate its value, and rarely recognize our obligations to it; existing civilizations would be impossible without it, and if human ingenuity finds no substitute for it they will perish with it.

The steam-engine is a machine which has been the prolific parent of other machines. It has caused the invention and construction of the immense plant of ingenious power-tools employed in its own fabrication; it has caused the improvement of metallurgy as a science and of the various methods of metal manufacture as an art; it may be said to have created whole branches of important manufactures, and to have been the occasion of the invention of the immense mass of highly diversified machinery by means of which these manufactures are practised; and, last and greatest, it has stimulated and directed the human intellect as nothing else ever has, and has done more to advance human nature to a higher plane than all which statesmen, generals, monarchs, philosophers, priests, and artists have ever accomplished, in the vast interval which separates original man

from the man of to-day. It has raised man from an animal to something approaching what a great intelligence should be, by simply placing in his hands a limitless physical power capable of application in every conceivable direction and to every conceivable purpose.

These words are no extravagant encomium : they are a simple statement of momentous facts, which, however, the mass of mankind seems so little to understand and appreciate, that I have ventured to give them record in a humble endeavor to prevent their being entirely overlooked, and with a hope of their eventual recognition.

Contemporaneous historians have but scantily drawn attention to the immense influence exerted upon modern history by the steam-engine. They follow in the same well-worn ruts, giving dubious descriptions of battles, names of monarchs and of statesmen, lists of decrees and laws, no end of political negotiations and intrigues, and the whole array of puppets who seem to push the car of time, while they are only flies upon its wheels. The real shaping cause of the march of modern events and of the great industrial progress of the times has but trivial recognition in the literature which pretends to account for what has happened, or to predict what may ensue. One of the peculiarities of the genesis of the steam-engine is, that it seems to have been more in the nature of a creation than of an evolution; for it was carried by its inventor, both as regards principles and practice, to a wonderful state of completeness. Very little has been added by his successors to his mechanical details or his various combinations of them. The invention seems to have nearly realized the birth of Pallas. The only modification in which he was not concerned is that of using the same steam in successive cylinders of increasing capacities, thus forming what may be termed, for the sake of distinction, the multiple cylinder engine as opposed to the single cylinder engine. The original multiple cylinder engine of Hornblower, brought out in 1781, and since known as the compound engine, and, by extension of the principle, as the triple expansion engine and the quadruple expansion engine, had thus a beginning almost coeval with the single cylinder engine of Watt. After much litigation it was declared to be an infringement on Watt's patents covering the use of steam expansively, and it passed out of use. It did not, in fact, give any economic gain over

the single cylinder engine, as the pressure of the steam was the same in both and only a few pounds above the atmospheric pressure, limiting the measure of expansion for maximum economy to about one and a half times. With this low pressure of steam, and for the small powers used in those days, there was no mechanical difficulty in developing the whole power in one cylinder with all the economy possible. To obtain higher economy, higher pressure was a necessity, and pressure is solely a question of boilers. At that time the art of boiler-making was so inchoate that sufficient strength of generator could not be obtained for greater pressure, and the development of the steam-engine could not progress much, if any, faster than the art of boiler-making; in fact, no one improvement in mechanics can advance much beyond the general front of what may be termed the industrial progress of the age. Aided by the improvement in the boiler-maker's art, the conspicuous advance which has been made with the steam-engine is the direct result of the higher pressures of steam used.

The economic necessity for employing these higher pressures has brought into vogue again the multiple cylinder engine, which enables the steam to be used with a regimen not practicable with the single engine, and this regimen is attended with enormous economic gains. In the first place, what may be termed a "given quantity of pressure"—that is to say, the product of a given weight of steam by its pressure—is larger proportionately to the heat required to evaporate that given weight, the higher the pressure at which it is evaporated. The heat per pound of water vaporized from a given temperature, it is true, increases with the pressure, but the *quantity* of pressure produced under the greater pressures by a given quantity of heat increases in a higher ratio. The gain thus derived in the production of the pressure is very considerable.

Taking 50 pounds per square inch above the atmosphere as that usual with single engines of anything above small dimensions, and 150 pounds above the atmosphere as an easily worked pressure with multiple cylinder engines, the gain in heat by the higher pressure used is about one-twelfth: a significant amount, but much less than what is additionally gained by the advantageous use of a greater expansion of the steam made possible by the greater pressure.

With the 50 pounds pressure, no gain is obtained by expand-

ing the steam more than about three times, while with the 150 pounds pressure the expansion can be advantageously carried to about six times.

The result of both these economies is, that the multiple cylinder engine of the triple expansion kind produces the horse-power with about two-thirds the coal that the single cylinder engine does. Or, otherwise expressed, the single cylinder engine, under the given conditions, would require about fifty per cent. more fuel for a given power than the triple expansion engine. These are the mean figures for ordinary practice, which may be varied considerably for extreme and exceptional cases. The gain would be much greater than stated, were it not that the higher pressure is accompanied by higher temperature, and therefore the gases of combustion must leave the boiler at a correspondingly higher temperature. Thus the economic vaporization of the boiler is less with the 150 pounds pressure than with the 50 pounds. Obviously, too, the higher temperature is accompanied by greater heat radiations from all steam surfaces, and the higher pressure by greater steam leakages past the valves and the pistons of the cylinders.

If the original steam-engine was the greatest boon mankind has ever received, an increase of its value by one-third over its best development should add proportionately to the benefaction; and such is the industrial effect of the modern steam-engine in its most advanced stage. The engineering world has "improved upon its heritage and vastly bettered its instruction." But it cannot proceed much further on the same lines, for with much higher pressure than has been already used the temperature of the steam would be too great to permit the metals to work satisfactorily on each other, while all the deducting losses would increase in a more than corresponding ratio.

The consequences of decreasing the cost of power by so large a fraction as one-third are very far-reaching, far beyond the mere cheapening to that extent of products already manufactured; for it allows other manufactures and other great works to be undertaken, which, with the reduced cost of power, become remunerative, but which at a higher cost would not have been undertaken. The benefits of cheapening power increase in a geometrical ratio: they radiate as from a centre.

This great improvement in the steam-engine, adapting it to higher possibilities and greater radius of action, has carried with

it all matters germane to it, and not the least among these is the enormous impetus and extension which it has given to mechanical science and art everywhere, making the engineer, by whatever name or title his specific work may designate him, the most potent factor in the world's progress, and "in the great work" —quoting from one of my eminent predecessors—"of emancipating mankind from the trammels of his animal nature."

Following as a natural sequence this recital of the potent influence of the steam-engine upon man's social and physical conditions comes the question, Is it to continue as the great power-producing machine of the future? Can the inventive mind of man and his artful hand bring into being any other device as a substitute for it, that will do its work cheaper, better, and more handily?

To give answer to this is to say how it can be done, and as yet none is ready with a reply. Without doubt, there are still "more things in heaven and earth than are dreamed of in our philosophy," but in the contemplation of a solution of this question, that already dreamed of is the limitation of our resource. Already we are beginning to avail ourselves of the enormous energy of water-power, now going to waste, through the convenience of electrical transmission and distribution, and the hand of the "Wizard" has drawn faint electrical energies direct from the combustion of fuel.

The winds and the tides and the rays of the sun have locked up within themselves enormous stores of power, waiting, perhaps, for the ingenuity of man to unbind and convert them to his uses.

But, when all shall have been realized which these as yet unused resources offer to man, when all man's present knowledge shall have ended in fruition, the steam-engine, from its portableness, its convenience of application, and its self-containedness, will still remain man's valued servant, the grandest conception of the human mind, the great conservator of the human race.

DVI.*

TESTS OF DRIVING BELTS.

BY SAMUEL WEBBER, CHARLESTOWN, N. H.

(Member of the Society.)

A SERIES of tests has recently been made by the writer upon the practical driving capacity of various belts. He would express his obligations at the outset to the Page Belting Co., of Concord, N. H., at whose instance the tests were begun, and to whom he is indebted for the outlay for the apparatus used for the purpose.

The belts were driven from a shaft on the upper floor of the shops, which also carried several other driving pullies, conveying power to a bark mill, and other machinery; and as the engine was fully loaded, the speed was irregular, and it became necessary at times to stop some of this machinery, and make the tests after it could be thrown off in order to get the full capacity of the belt. This will account for the variations in speed noticed.

It was also impossible to get on the driving shaft any automatic apparatus for determining its speed, and the speed of that shaft and the subsequent "*slip*" were ascertained as carefully as possible by a skillful mechanic who assisted me.

The instigators of the test prepared an excellent arrangement for the brake and friction pulley, which were mounted on a frame sliding on ways, which could be drawn up by screws, with tension balances interposed, so as to ascertain the exact tension on the whole belt at the beginning of each test; and when, as was the case at first with the new belts, the belt stretched, so as to reduce that tension, the frame was screwed out to the initial tension before beginning the next one. I have not attempted to separate the tensions of T^1 and T^2, as I am

* Presented at the New York Meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the Transactions.

very skeptical as to accuracy of any such measures, except by a dynamometer inserted in the belt, and which could not be seen when it was in motion.

In spite of some adverse criticism as to the method of recording tests made on the presentation of a former paper by me on this subject, I present this one in the same form, as I conceive the only value of a belt to be its driving capacity, and the simplest way of expressing that is by the velocity per minute at which each inch of width will transmit a horse power. The "coefficient of friction" is obtained by dividing the foot-pounds lifted by the strain on the belt, and will be found to agree very closely with the conclusions already arrived at by earlier and careful experimenters.

The belts were all 6″ wide, 29′ 3″ long, and their weight is given in the tables.

The shafts were on the same level, 12 feet from centre to centre, when separated, and the driving pulley was 30″ diameter, the driven one 12″, so that the arc of contact was rather less than 180°. The strain came on the under side, but there was very little sag to the upper side with such short belts, except in the case of some of the tests of link belts, which were purposely tested so as to allow them to take a much larger hold on the pulley. The link belts were "*hinged*" in the middle, so that they did not slip off from the pulley, and gave much better results than in my previous tests, but from their own weight heated the shaft of the friction pulley, in spite of lubrication.

The "slotted" belt had about half the punctures, and those about half the size of those in the "perforated" belt; and in both cases the slip appeared to be less, and more uniform, than in the solid belts. The belts were certainly not nearly so much weakened by these perforations as by the lace-holes.

We did not intend to carry any of the tests above a strain of 83⅓ lbs. per inch, which we considered a fair working pressure for the light double belts tested; but in the case of the slotted, or perforated belts, we extended this somewhat, to test them fully. The "leather-lined canvas" belt gave excellent results as before, but its opponents object to it, from the difficulty of making perfect joints by lacing, and it will be seen that the "slotted" leather belt called the "Eureka," when dressed so as to be perfectly supple, gave very nearly as high results, and showed about the same coefficient of friction, which diminished

a little in the last test, when the strain was increased from 83⅓ to 91⅔ lbs. per inch.

I should state that the weights given in the tables were applied at the extremity of a lever, being the radius of a 10-foot circle, and that the lift was positive, and not a pressure on a platform scale.

The same speed counter and bell used at Tolland were used to ascertain the revolutions of the friction pulley, and the same "Karchner" scales to determine the strain on the belts.

This paper is not intended so much to provoke discussion as simply to place on record some results which may be found valuable by future experimenters.

The writer hopes yet to be able to find an opportunity to make such experiments himself, where he can have sufficient power at his control to make them uniform in velocity, and determine the slip with greater accuracy.

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 8, 1891.

Driver, 30 inches. Driver P., 30 inches. 6-inch "Schieren link" belt 29 feet 3 inches long. 57¾ lbs.

Initial Strain per Inch.	Lbs. in Scale.	Rev. per Minute. Pulley.	Horse Power.	Feet per Minute. Speed. Pulley.	Rev. per Minute. Driver.	Feet per Minute.	Slip.	Coefficient Friction.	Feet per Min. for 1 H.P. per In. of Belt
Lbs.	Lbs.						Per cent.		
41.66	21.5	545	11.72	1,713	327	2,567	33.	.301	1,316
50.	21.5	571	12.275	1,795	291	2,282	12.14	.296	1,115
58.3	21.5	566	14.32	2,093	293	2,300	9.	.294	962
60.	26.5	706	18.71	2,219	314	2,465	10.	.329	790
66.66	26.5	682	18.07	2,143	314	2,465	13.	.320	812
66.66	26.5	706	18.75	2,219	288	2,261	2.	.380	724
66.66	26.5	750	19.875	2,307	320	2,512	8.	.362	759
66.66	31 5	666	20.96	2,093	293	2,300	9.07	.417	660
75.	31.5	723	22.77	2,272	331	2,598	12.5	.321	683
75.	36.5	666	24.31	2,093	293	2,300	9.07	.388	568
83.⅓	36.5	682	24.89	2,143	303	2,378	10.	.345	573
83.⅓	41.5	545	22.6	1,713	260	2,041	16.	.365	547
Bearings heated, and speed down. Load too heavy for main belt from below. April 13th. Same belt "slack as in pictures."									
									190° contact.
22.¼	17.5	566	9.90	1,779	250	1,962	9.3	.616	1,189
22.¼	17.5	822	14.38	2,583	322	2,763	6.5	.636	1,063
22.¼	20.	741	14.8	2,329	327	2,567	9.2	.700	1,040
22.¼	22.	706	15.9	2,219	352	2,763	20.	.700	1,040
Stopped from slip.									

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 8, 1891.

Light "Page link" belt, $\frac{9}{16}$ inch thick. 48½ lbs.

Initial Strain per Inch.	Lbs. in Scale.	Rev. per Minute.	Horse Power.	Feet per Minute. Driven.	Rev. per Minute. Driver.	Feet per Minute. Driver.	Slip.	Coefficient Friction.	Feet per Min. per H.P. per Inch.
Lbs.	Lbs.						Per cent.		
50.	21.5	760	16.34	2,389	353	2,771	12.	.324	1,016
50.	26.5	723	19.16	2,272	312	2,449	7.	.365	767
62.½	31.5	577	18.17	1,813	257	2,017	10.	.396	666
75.	31.5	666	20.98	2,093	250	1,962	10.	.391	560
April 9th.									
75.	31.5	462	14.55	1,452	200	1,570	7.5	.340	647
75.	31.5	625	19.68	2,064	326	2,559	19.	.282	800 Belt Stretched
75.	31.5	714	22.49	2,249	325	2,553	12.	.323	680
83.⅓	36.5	660	24.09	2,075	291	2,284	9.	.348	569
83.⅓	36.5	666	24.31	2,093	297	2,331	10.2	.344	576
Slight strain, as pictured.									
25.	5.	811	4.55	2,549	372	2,920	13.	.170	3,842
25.	7.	800	5.60	2,514	375	2,943	14.5	.209	3,154
25.	10.	Slipped and stopped.							

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 11, 1891.

"Schieren perforated belt." 18½ lbs.

Initial Strain.	Lbs. in Scale.	Rev. per Minute.	Horse Power.	Feet per Minute. Driven.	Rev. per Minute. Driver.	Feet per Minute. Driver.	Slip.	Coefficient Friction.	Feet per Min. per H.P. per Inch.
Lbs.	Lbs.						Per cent.		
66.⅔	20.	682	13.64	2,143	281	2,206	2.85	.255	972
66.⅔	23.	600	13.8	1,885	257	2,017	6.5	.282	877
75.	23.	741	17.04	2,329	302	2,371	2.	.263	831
75.	25.	741	18.5	2,329	306	2,402	3.	.283	780
75.	27.5	618	17.	1,942	279	2,190	11.3	.286	773
83.⅓	27.5	606	16.6	1,904	259	2,033	6.	.270	734
87.½	27.5	600	16.5	1,885	259	2,033	7.	.256	734
96.	30.	495	14.85	1,556	212	1,664	6.5	.256	673
96.	32.5	541	17.48	1,705	219	1,719	?	.298	590
Shut off bark mill.									
96.	35.	660	23.10	2,074	281	2,206	6.	.300	573
96.	37.5	666	24.98	2,094	282	2,213	5.	.324	532
96.	40.	638	25.52	2,005	275	2,118	5.	.346	497
96.	42.	606	25.45	1,904	257	2,017	5.6	.363	473
96.	45.	526	23.67	1,653	221	1,735	4.7	.391	440
Stopped for want of power.									

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 10, 1891.

Light double leather (Eureka) dynamo belt. 21.5 lbs. Page Belting Co.

Initial Strain.	Lbs. in Scale.	Rev. per Minute.	Horse Power.	Feet per Minute. Pulley.	Rev. per Minute. Driver.	Feet per Minute. Driver.	Slip.	Coefficient Friction.	Feet per Min. per H.P.
Lbs.	Lbs.						Per cent.		
41.66	20.	645	12.9	2,027	282	2,210	8.3	.385	1,024
50.	20.	724	14.48	2,275	308	2,413	5.7	.330	924
50.	25.	660	16.5	2,074	281	2,206	6.	.409	800
58.33	25.	660	16.5	2,074	282	2,210	6.	.353	800
58.33	25.	690	17.25	2,169	282	2,210	2.	.363	769
58.33	30.	612	18.36	1,927	283	2,215	13.	.390	724
66.66	30.	720	24.9	2,263	318	2,496	9.3	.411	600
66.66	35.	594	20.79	1,867	267	2,096	11.	.409	600
75.	35.	741	25.93	2,329	322	2,527	7.8	.376	585
75.	40.	606	24.24	1,904	270	2,119	10.	.420	522
83.½	40.	674	26.96	2,118	286	2,245	5.6	.396	500
83.½	45.	539	23.83	1,666	218	1,947	14.	.404	490
				Stopped. *Overloaded.*					

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 11, 1891.

Same double (Eureka) dynamo belt, waterproofed. 22 lbs.

Initial Strain.	Lbs. in Scale.	Rev. per Minute. Pulley.	Horse Power.	Feet per Minute. Pulley.	Rev. per Minute. Driver.	Feet per Minute. Driver.	Slip.	Coefficient Friction.	Feet per Min. per H.P. per Inch.
Lbs.	Lbs.						Per cent.		
66.66	20.	870	17.4	2,734	357	2,802	2.4	.256	966
66.66	25.	845	21.1	2,656	350	2,747	3.3	.334	780
66.66	30.	811	24.33	2,549	342	2,684	5.	.374	663
66.66	35.	770	26.95	2,420	327	2,567	5.3	.433	572
81.25	40.	660	26.4	2,074	283	2,201	5.8	.396	500
75.	35.	760	26.6	2,389	325	2,551	6.45	.380	576
83.½	35.	770	26.95	2,420	321	2,520	4.	.353	561
83.½	40.				Belt slipped badly.				
96.	40.	674	26.96	2,118	284	2,289	5.	.337	500
96.	40.	666	26.64	2,094	282	2,213	5.	.337	500
				Stopped here. No great difference.					

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 13, 1891.

Same double (Eureka) dynamo belt, "slotted."

Initial Strain.	Lbs. in Scale.	Rev. per Minute.	Horse Power.	Feet per Minute. Pulley.	Rev. per Minute. Driver.	Feet per Minute. Driver.	Slip.	Coefficient Friction.	Feet per Min. per H.P. per Inch.
Lbs.	Lbs.						Per cent.		
52.	20.	600	12.	1,885	252	1,978	4.7	.320	989
52.	25.	800	20.	2,514	333	2,613	3.8	.444	784
52.	30.	723	21.69	2,272	301	2,363	3.8	.484	653
62.½	30.	706	21.18	2,219	298	2,339	5.1	.398	663
62.½	35.	682	23.86	2,143	283	2,221	3.5	.472	559
75.	35.	706	24.71	2,219	292	2,292	3.2	.395	556
75.	35.	750	26.25	2,357	319	2,504	5.9	.384	573
75.	40.	700	28.1	2,200	292	2,292	4.	.463	500
83.½	40.	660	26.40	2,075	292	2,292	9.5	.440	472
				Repeated three times with same result, and "Dressed" belt.					
83.½	40.	770	30.8	2,420	315	2,473	2.	.411	482
83.½	40.	770	30.8	2,420	327	2,567	5.7	.400	500
83.½	45.	750	33.75	2,357	312	2,449	4.	.455	425
91.66	45.	750	33.75	2,357	310	2,433	4.	.458	422
				Lighter strain. Bark mill off.					
50.	32.5	857	27.85	2,693	352	2,763	2.5	.554	600
50.	35.	822	28.77	2,583	344	2,700	4.4	.586	563
				Stopped at dark.					

RECORD OF BELT TESTS. CONCORD, N. H. APRIL 9, 1891.

Page's cotton leather belt, 29 feet 3 inches. 6 inches wide. 26½ lbs.

Initial Strain.	Lbs. in Scale.	Rev. per Minute.	Horse Power.	Feet per Minute. Speed. Pulley.	Rev. per Minute. Driver.	Feet per Minute. Belt.	Slip.	Coefficient Friction.	Feet per Min. per H.P. per Inch.
Lbs.	Lbs.						Per cent.		
41.66	21.5	800	17.20	2,514	338	2,653	5.	.428	924
41.66	26.5	750	19.87	2,307	323	2,535	8.1	.517	766
46.	31.5	666	20.98	2,093	281	2,206	5.	.570	630
50.	31.5	638	20.10	2,005	287	2,253	11.	.490	673
54.	31.5	606	19.09	1,904	254	1,994	4.4	.486	628
				Threw off bark mill.					
58.33	31.5	896	28.22	2,816	370	2,904	3.	.458	618
58.33	36.5	845	30.42	2,655	368	2,889	8.	.496	570
58.33	40.5	779	31.16	2,448	350	2.747	11.	.534	530
									Main belt slipped.
75.	40.5	531	21.24	1,669	248	1,946	14.	.400	550
75.	40.5	779	31.16	2,448	324	2,543	3.	.447	490
75.	45.	750	33.75	2,307	297	2,331	1.	.531	414
83.⅓	45.	760	34.20	2.389	321	2,520	6.	.447	442
83.⅓	50.	638	31.9	2,005	266	2,088	4.	.504	393
91.66	50.	714	35.7	2,244	306	2,402	6.	.446	403
91.66	55.	618	33.99	1,942	264	2.072	6.	.493	366
91.66	62.5				Slipped and stopped.				

Canvas belt, with "fulled" leather lining. One warp thread left out in center to form "hinge."

DVII.*

THE LIMIT OF PROPELLER EFFICIENCY AS DEPENDENT ON THE SURFACE FORM OF THE PROPELLER.

BY W. F. DURAND, ITHACA, N. Y.

(Member of the Society.)

THE author has elsewhere † proved a simple proposition relating to propeller efficiency. Inasmuch as the proof is short and the proposition is fundamental to the present inquiry, we will here repeat it in generalized form.

Let *ab* (Fig. 1) denote elements at various angles of obliq-

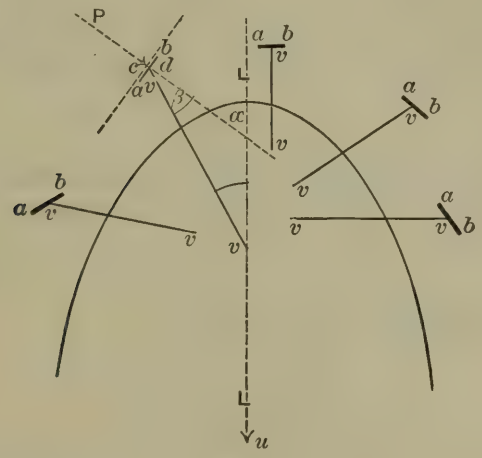

FIG. 1.

uity to *vv*, their directions of motion relative to the ship, such directions being at various angles to the longitudinal LL. Let α denote the angle between the normal to *ab* and LL, and β the angle between the same normal and *vv*. It will be understood that

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† Vol. IV., No. 1, of the *Journal of the Society of Naval Engineers*.

the problem deals with space geometry, and that α and β are not in general in the same plane, nor in that of the paper. Now, omitting tangential forces on ab and without assuming anything relative to the law according to which the normal force varies, call the latter at any instant P. Then,

$P \cos \alpha =$ longitudinal component.
$P \cos \beta =$ component in direction of motion vv.

Let v denote the velocity of ab along vv relative to the ship, and u the velocity of the ship along LL,

Then, $P \cos \alpha \, u =$ useful work.
and, $P \cos \beta \, v =$ total work.

$$\text{The efficiency} = \therefore \frac{u \cos \alpha}{v \cos \beta} = \frac{u}{v \cos \beta \sec \alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now if we suppose that each of these elements ab is supported on its working face by a *smooth* unyielding surface, it is readily seen that the velocity of the ship along LL would be

$$v \cos \beta \sec \alpha.$$

The difference between this and the actual velocity u is then the apparent slip, and if this, expressed as a per cent. of

$$v \cos \beta \sec \alpha,$$

be called s, it follows that the efficiency

$$\frac{u}{v \cos \beta \sec \alpha} = 1 - s.$$

Throughout the article it will be remembered that the term *slip* has reference to the apparent slip as commonly called, and the letter s to the slip per cent. as defined above. It is also to be remembered that the proposition refers to the *limiting* efficiency, or the efficiency when forces acting along the surface of an element, *i.e.*, frictional forces, are considered as absent. We have also considered the element as subject to a certain net pressure, P, on its working face, C. But P is really the resultant of two normal forces, one R on C and one S on D, such that at each instant $R - S = P$. Now it is evident that the same

reasoning may be used for R and S individually as was used for their resultant P, and that the efficiencies relative to R and S will be the same, and the same as for their resultant P. The work relative to R will be + and that relative to S −, the sum being the net work relative to P as before. We have ∴ the following proposition:

The efficiency (friction neglected) of any element of the surface of any propeller is $(1 - s)$, the slip per cent. referring, of course, to the element in question, and the work being estimated relative to the total normal pressure upon it.

It will be noted that this proposition is independent of the direction of flow of water to the element, of its velocity relative to the water, of its location, and of the normal pressure upon it, and of the law according to which the latter varies. The limiting efficiency is ∴ a function simply of the geometrical configuration in space of the moving propeller, and independent of dynamic and other considerations.

We will now apply this proposition to various forms of propellers.

1. The propeller of uniform pitch considered as a helicoidal surface without thickness.

From the second supposition the two faces at any point are mutually parallel. Let the propeller be working under such conditions that the slip per cent. is s. The limit of the efficiency of each and every element is then exactly $(1 - s)$. It follows that the limiting efficiency for the propeller as a whole is the same, and this holds, no matter how much or how little work may be done by or on each element. This is evident, but a simple proof may be given, as follows:

Let w_1, w_2, w_3, etc., be the net amounts of work absorbed by successive elements, considering here an element as comprising the two opposite parallel faces. Then $(1 - s)w_1$, $(1 - s)w_2$, etc., are the corresponding amounts of *useful* work received from each such element. Therefore Σw = total gross work and $\Sigma(1 - s)w = (1 - s)\Sigma w$ = total useful work. Hence,

$$\text{Efficiency} = \frac{(1 - s)\Sigma w}{\Sigma w} = 1 - s.$$

2. Let the propeller be again a surface of no thickness, but of variable pitch. Let it be working under such conditions that

the slip of the various elements varies between s_1 and s_2. Consider $s_1 > s_2$. The limiting efficiency of the various elements will then vary from $(1 - s_1)$ as a minimum to $(1 - s_2)$ as a maximum.

As above, denote the work absorbed by an element by w, and consider likewise the element as comprising the two opposite parallel faces at the given point. The efficiency as a whole will then have as its limiting value the expression,

$$e = \frac{\Sigma(1 - s)w}{\Sigma w}.$$

In this expression, s being a variable cannot be removed from the operation of integration, and therefore the expression cannot be further reduced in its general form. We can say, however, that if all the values of w are considered positive, the resultant value of e will lie between $(1 - s_1)$ and $(1 - s_2)$, and that the exact value will depend on the distribution of the work among the various elements; *i.e.*, over the surface of the blade. If the elements having high efficiency are those which absorb a large share of the work, the general value will be relatively high, or near $(1 - s_2)$; *vice versa*, it will be relatively low, or near $(1 - s_1)$.

We have next to inquire regarding the existence of negative values of w. Their physical meaning is this:

Positive values refer to work absorbed by the element from the engine. Therefore, negative values must refer to work given to the engine by the element. In order that the work may be negative the excess of pressure must be on the forward side of the element, and therefore the water must flow to it on that side, rather than on the after side, as with elements working normally. Their effect is, therefore, to help the engine, or rather to decrease the net amount of work absorbed from it, and also to decrease the thrust, and therefore the useful work realized. The quantitative measure of this effect depends on the particular problem, and cannot be expressed in general terms. We may see the principles involved, however, by considering the blade as made up of two parts: one with reference to which the work is positive, and the other with reference to which it is negative. Let w_1 and w_2 represent the positive and negative works respectively, and e_1, e_2 the corresponding average efficiencies. Then the resultant efficiency is

$$e = \frac{e_1 w_1 - e_2 w_2}{w_1 - w_2} = e_1 + \frac{w_2}{w_1 - w_2}(e_1 - e_2) = e_2 + \frac{w_1}{w_2 - w_1}(e_2 - e_1).$$

We may distinguish four cases :

(1) $e_1 > e_2$ and $w_1 > w_2$, in which case $e > e_1$.
(2) $e_1 > e_2$ " $w_1 < w_2$, " " " $e < e_1$.
(3) $e_1 < e_2$ " $w_1 > w_2$, " " " $e < e_2$.
(4) $e_1 < e_2$ " $w_1 < w_2$, " " " $e > e_2$.

These may be generalized thus :

If the elements of greater efficiency absorb also the greater work, and *vice versa*, the resulting efficiency is greater than either e_1 or e_2 ; while if the elements of greater efficiency absorb the lesser work, and *vice versa*, the resulting efficiency is less than either e_1 or e_2. That is, of the two efficiencies e_1 and e_2, the resultant efficiency is greater than the greater or less than the lesser, according as the greater work corresponds to the greater or to the lesser of these two partial efficiencies. We know, however, that the positive work must be greater than the negative, since, on the whole, work is absorbed from the engine. Therefore, $w_1 > w_2$, and it follows that the average efficiency of the elements whose work is positive will be raised by the combination with elements having negative work if the positive efficiency is the greater, and lowered in the reverse case.

In the actual case of a screw propeller, the portions of the blade which are more likely to receive the greater pressure on their forward faces are those of least pitch, or those on the leading edge A (Fig. 2), as in the case of a blade with axially expanding pitch. But these elements are those of minimum pitch, and, therefore, of minimum apparent slip, and, therefore, of maximum limiting efficiency. In such a case, therefore, we have the negative work done at the higher efficiency, and, hence, the resultant efficiency will be *less* than that due to the after parts of the blade, relative to which the work is positive.

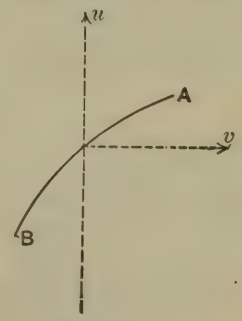


FIG. 2.

We will next take up the case of a blade having thickness. We shall here find it convenient to consider as the element, a

single small portion of the surface. The expression for efficiency as a whole will be of the same general form as before,

$$e = \frac{\Sigma(1 - s)W}{\Sigma W};$$

the integration being extended over the entire surface of the blade, and involving both positive and negative values of W, which here represents the *gross* work absorbed by the element, or, in other words, the transverse work due to the total normal pressure upon it. We will first suppose the after or driving face to be a helicoidal surface of uniform pitch, while the front surface is simply that which results from the application of the thickness. Let the diagram (Fig. 3) represent the cross section of such a blade. Let it be working under such conditions that

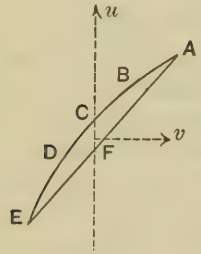


FIG. 3.

s is the slip of the face AFE. Then all portions of this face will have the same limiting efficiency $(1 - s_1)$, which we may call e_1. Elements from E to D will have a limiting efficiency considerably less than e_1, those from D to C slightly less, at C it will be equal to e_1, and from C to A greater than e_1, possibly becoming greater than unity for points near A. Suppose next the two surfaces, front and back, paired off into a series of elements obtained by erecting normals to the perimeters of the elements of AE. Let e_2 denote the efficiency of the back element, and $w_1 w_2$ the two amounts of work involved. Then the resultant efficiency for any pair will be

$$e = \frac{e_1 w_1 - e_2 w_2}{w_1 - w_2},$$

the same in form as that which we have already discussed for the case of a surface of no thickness with elements of positive and negative work. This value, it will be noted, is true independent of the difference in area of the two elements. Now, under usual conditions, $w_1 > w_2$. The area of an element on the back face, it is true, is slightly greater than its fellow on the front face, but this difference would be far more than overcome by the fact that w_1 is the work of the driving face, which in general meets the flow of water to the propeller and experiences therefrom a normal pressure far greater than that on the back

face. Assuming, therefore, $w_1 > w_2$, let us next take $e_1 > e_2$ as for the elements on the following half of the blade. As before seen, the efficiency for the pair will be greater than e_1. If, *vice versa*, $e_2 < e_2$, as for the elements on the leading half, then similarly $e < e_1$. The question now as to whether the efficiency as a whole is greater or less than e_1 depends on the general distribution of work over the surface of the blade, and more especially as to whether the resultant efficiency e is more raised by the influence of the following pairs of elements than it is lowered by that of the leading pairs, or *vice versa*. Experiment has clearly shown that in the case of such a blade the leading portions of the surfaces, both front and back, are likely to be subjected to a higher normal pressure than the following portions. It may therefore result that the *net* pressures, and hence the *net* works, are about the same for both portions. Taking now the value of e, we have

$$e = e_1 + \frac{w_2}{w_1 - w_2}(e_1 - e_2).$$

We may note that for the forward and after parts of the blade as a whole, $(e_1 - e_2)$ is about the same numerically, being negative in one case and positive in the other. If, then, $(w_1 - w_2)$ and $(e_1 - e_2)$ be taken as the same for both parts, it follows that the term $\frac{w_2}{w_1 - w_2}(e_1 - e_2)$ varies numerically, simply as w_2. Hence its negative value for the forward part of the blade will be greater than the positive value for the after part. Hence the decrease in e due to ABC will be more than the increase due to EDC. It follows that we shall have about equal amounts of net work for the two parts: that for the forward part being done at a decreased, and that for the after part at an increased efficiency, the amount of decrease being greater than that of increase. Under these conditions, which seem natural, the resultant mean efficiency will be somewhat less than that due to the front face alone.

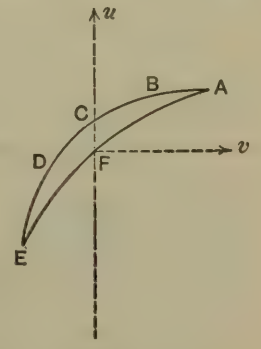


FIG. 4.

As the next case, and the most general, we may assume the

pitch, and therefore the slip, and therefore the efficiency, to vary over both faces. Let the diagram (Fig. 4) represent a cross section of such a blade. The general expression for efficiency will be as before,

$$e = \frac{\Sigma w(1 - s)}{\Sigma w}.$$

The elementary efficiencies both of the front and back faces will decrease from A to E. Let the front and back faces be paired off in elements as before. For the resultant efficiency of any such pair, we shall have the same value as above:

$$e = \frac{e_1 w_1 - e_2 w_2}{w_1 - w_2}.$$

Assuming, again, that $w_1 > w_2$, it follows that for the leading half of the blade ACF, the efficiency will be less than that for the surface AF, while for the following half, CFE, it will be greater than that for the surface EF. For such a surface as AFE the normal pressures will be distributed with greater uniformity than in the case of a surface of uniform pitch, but on the back surface the pressure on ABC will probably exceed that on CDE. If then we assume the distribution of the pressure over AFE as nearly uniform, we may omit the influence on w_1 of the variation in direction of the elements of AGE, and assume, therefore, the distribution of w_1 as also nearly uniform, and hence the same for the forward and after parts.

Also, as before, $(e_1 - e_2)$ is the same numerically. Referring to the value of efficiency,

$$e = e_1 + \frac{w_2}{w_1 - w_2}(e_1 - e_2).$$

it follows that for the forward part, where w_2 is relatively large, $(w_1 - w_2)$ will be relatively small and $\frac{w_2}{w_1 - w_2}(e_1 - e_2)$ will be relatively large, due to variation in both numerator and denominator, and therefore the efficiency of the forward part of the blade will be less than that of AF by a relatively large amount. Similarly for the after part, where w_2 is small, $w_1 - w_2$ will be relatively large, and the amount of increase in efficiency will be relatively small in comparison with that of EF. Therefore, on the whole, we shall have a small amount of work done at a much

decreased efficiency combined with a large amount done at a slightly increased efficiency.

The result may well be that the mean final efficiency is but slightly changed relatively to the value for the front face *AFE*.

The reasoning in these cases has reference directly to a band of area at some one constant radial distance from the centre. For similar bands at other distances we should expect results of a similar character, though perhaps varying in relative amount.

For the cases of blades with thickness, the reasoning as to the actual value of the final efficiency is somewhat inconclusive, for such value depends so much upon the especial circumstances of the case that it does not admit of general treatment. It seems conceivable, in fact, that with certain forms and with certain circumstances there might be an *increase* of limiting efficiency, due to thickness, rather than a *decrease*.

In thus comparing the efficiencies of a blade with and without thickness, it has been assumed that the conditions of the driving face as regards slip, and therefore efficiency, are the same both with and without the thickness. If, however, we take into account the additional consideration of the effect on the *thrust* of the addition of thickness, we find a further cause for a decrease in efficiency. This appears as follows: The stream lines in flowing about the blade close in more or less imperfectly behind it, thus giving rise to the difference in pressure between the front and back faces. Now the more completely the space back of the driving face is filled in with the material of the blade, the more perfectly will the stream lines be able to close in upon the blade, and the greater will be the normal pressure on the back face. It follows that the resultant of this distributed pressure in a direction normal to the blade will also be increased, and therefore the net normal pressure will be *decreased*. But it is this net normal pressure from which we derive the thrust, and it therefore follows that the addition of thickness will, at constant speed of revolution, result in a decrease of thrust, a decrease of speed, an increase of slip, and a decrease in all the elementary efficiencies, and therefore a decrease in the efficiency as a whole.

We have thus endeavored to show:

(1) That the limiting efficiency of the element of the surface of a propeller, working under any given conditions, is an abso-

lute geometrical quantity, depending solely on its direction and motion, and on the motion of the ship.

(2) That the limiting efficiency of an entire propeller, composed of helicoidal surfaces of the same uniform pitch, is equally simple and definite.

(3) That the limiting efficiency of propellers in general, whether considered as surfaces not truly helicoidal, or as solids such as are actually used, depends on the additional consideration of the distribution of work over their surfaces. The latter, being a subject of great complexity, and depending on the ship as well as on the propeller, does not admit of general analytical treatment. It is shown, however, that certain limits may usually be laid down between which the efficiency in any given case must lie; and in the case of solids, as actually used, it is shown that such suppositions as can be made lead to the natural conclusion that thickness in general is detrimental to efficiency.

DVIII.*

NEGATIVE SPECIFIC HEAT.

BY DE VOLSON WOOD, HOBOKEN, N. J.

(Member of the Society.)

SPECIFIC heat may be defined as the heat absorbed by unity of weight of a substance in raising its temperature one degree according to an assumed law of changes of pressure and volume. Conversely, if the temperature be lowered one degree, it will be the heat emitted.

Rankine divides specific heat into two parts, "real" and "apparent"; the former being that part of the heat transmitted which makes the substance hot, the latter that which accomplishes the former and also does work, external and internal. As the physicist does not deal with perfect gases, the specific heat found experimentally is always the "apparent." (Rankine's *Prime Movers*, pp. 245, 248, 306, 316, 317.) The above definition is no broader than one given by Rankine, for he says: "For gases, the mode of variation of the thermo-dynamic function with temperature may be regulated artificially in an arbitrary manner, so as to vary the specific heat in an infinite number of ways. It is customary, however, to restrict the term 'specific heat,' in speaking of gases, to two particular cases; that in which the volume is maintained constant, and that in which the pressure is maintained constant." (*Ibid.*, p. 316.) Clausius has applied the term to vapors constantly saturated during the change of temperature. In this paper we propose to discuss the properties according to the above general definition.

If dh represent the heat transmitted (absorbed or emitted) in ordinary heat units per pound of the substance in raising (or lowering) its temperature one degree, τ the absolute tempera-

* Presented at the New York meeting November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the Transactions.

ture, and c the specific heat of the substance according to any arbitrary change of pressure and volume ; then will

$$c = \frac{dh}{d\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If the substance be compressed or expanded adiabatically, no heat will be transferred to or from the substance, and hence, $dh = 0$, let c_a be the specific heat for adiabatic change (the subscript a being the initial letter of adiabatic); then,

$$c_a = \frac{0}{d\tau} = 0, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or the specific heat will be zero.

Let the change be isothermal, then will τ be constant and $d\tau = 0$, while dh will be finite. Then

$$c_t = \frac{dh}{0} = \infty, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or the specific heat for isothermal changes will be infinite. These results are true for all substances—gases, vapors, liquids, solids, or a mixture of these. Two practical cases occur in practice. Ice may be changed to water at constant temperature, and liquids may also be changed to vapors also at constant temperature ; and, at each of these changes, the specific heat will be infinite.

Representing isothermals and adiabatics by straight lines, in Fig. 5, the adiabatics being marked ϕ and the isothermals by τ, A the initial state, Aa and bc isothermals differing by unity, Ad horizontal, Ae vertical ; then will $jAdh$ represent the specific heat at constant pressure. Let the path Ad revolve about the initial state A, to the vertical Ae, then will $jAei$ represent the specific heat at constant volume, which, it will be seen, is less than that at constant pressure. For all paths in the angle bAa heat will be absorbed, and dh will be positive, and the temperature will be increased, and $d\tau$ will be positive ; hence for all paths in the first angle, the specific heat will be

$$c = \frac{+\,dh}{+\,d\tau} = a \textit{ positive value}, \quad . \quad . \quad (4)$$

beginning with infinity on the isothermal Aa, and diminishing as the path is revolved from Aa to the left, becoming zero on the adiabatic Ab.

If the path be Af, heat must be abstracted from the sub-

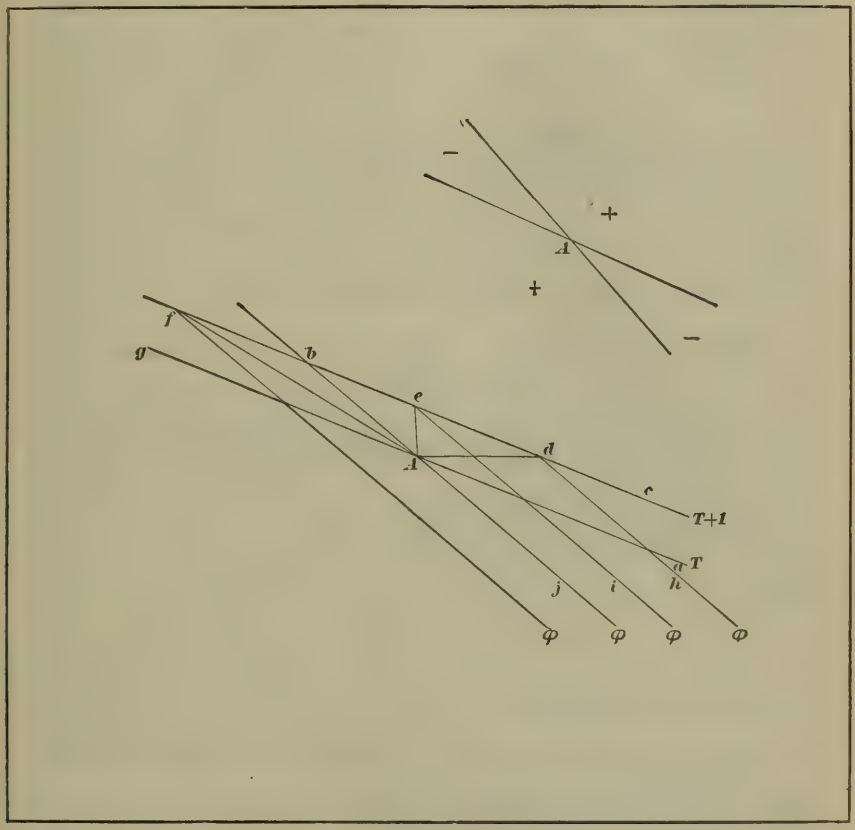


Fig. 5.

stance, the amount being $jAf\phi$, which will be negative, while $d\tau$ will be positive ; hence, for all paths in the second angle

$$c = \frac{-dh}{+d\tau} = a \text{ negative value} \quad . \quad . \quad (5)$$

and increases numerically from zero on Ab to infinity at Ag.

In the angle gAj, dh will be negative for all paths and the temperature will fall, or $d\tau$ will be negative ; hence

$$c = \frac{-dh}{-d\tau} = a \text{ positive value} \quad . \quad . \quad (6)$$

In the fourth angle jAa,

$$c = \frac{+ dh}{- d\tau} = a \text{ negative value} \quad . \quad . \quad . \quad (7)$$

These signs follow the same order as that of the tangent in trigonometry.

In imperfect gases, changes of molecular conditions take place, but the heat involved in producing these changes is usually small. But in a mixture of a liquid and its vapor these molecular changes sometimes involve considerable heat, since the relative proportions of vapor and liquid may vary. In some cases some of the liquid will be vaporized during a change of temperature, and in others some of the vapor may be condensed.

To find the specific heat of a mixture of a liquid and its vapor, let

s = the saturation constant, or the heat that must be transmitted in order to maintain unity of weight of vapor in a state of saturation during a change of temperature of one degree,—also called the specific heat of saturated vapor of constant weight,

c_1 = the specific heat of the liquid,

h_e = the heat of vaporization of the liquid;

then

$$s = c_1 - \frac{h_e}{\tau} + \frac{dh_e}{d\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

(Author's *Thermodynamics*, p. 147).

Let x = the fractional part of the pound of the mixture, which is vapor,

then will the heat absorbed in raising the temperature $d\tau$ be

$$dh = (1 - x)\, c_1 d\tau + xsd\tau + h_e dx \quad . \quad . \quad . \quad (9)$$

(*Ibid.* p. 146.) The value of h_e may be represented with sufficient accuracy for ordinary purposes by the formula

$$h_e = a - b\tau \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where a and b are constants. Equations (8) and (10) substituted in (9) give

$$c = \frac{dh}{d\tau} = c_1 - a\frac{x}{\tau} + h_e \frac{dx}{d\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

If the change of volumes and temperature be arbitrary, the relation of x to τ must be known before this formula can be reduced. Two cases will be considered.

Let the weight of vapor be constant during the changes of temperature, then $dx = 0$, and indicating that the weight is constant by the subscript $_w$, then

$$c_w = c_1 - a\frac{x}{\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

which gives the specific heat of a pound of fluid of which the x^{th} part is vapor and the remaining part liquid. Applying this to water, $c = 1$ and $a = 1436$;

$$\therefore c_w = 1 - 1436\frac{x}{\tau}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Let $x = \frac{1}{2}$ and $\tau = 718$, or on the Fah. scale 258°F.; then

$$c_w = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

This result indicates that the change will be adiabatic, and, indeed, it may be shown that the curve representing the relations between the volumes and pressures for different temperatures when there are equal weights of water and vapor will be tangent to the adiabatic at the temperature of 258°F.

For temperatures above 258°F., the specific heat in this case will be *positive*, and for temperatures less than 258°F. it will be *negative*. Hence, when one-half only of the fluid is vapor, and it be either compressed or expanded adiabatically from 258°F., vapor will be condensed.

If x be less than one-half, zero specific heat will exist at a lower temperature. If $x = 0.468$, c_w would be zero at about 212°F., and the specific heat would be positive for all higher values. If $x = 0$, $c_w = 1$ as it should, since the fluid will then be all liquid.

If $x = 1$, then

$$c_w = 1 - \frac{1436}{\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

which is the formula ordinarily given for the specific heat of vapor continually saturated. This is the case where the entire pound is vapor. For $\tau = 1436$, $c_w = 0$, and as this is the temperature of inversion, it follows that the specific heat of saturated steam *when no liquid is present* is always negative.

As a second application of equation (11), let the change be adiabatic, then $dh = 0$, and

$$h_e d\alpha = \left(a\frac{\alpha}{\tau} - c_1\right)d\tau,$$

which, being a linear differential equation of the first order, may be integrated. The value x thus found between assigned limits of temperature will be the amount of vapor generated if the temperature be increased, or condensed if the temperature be decreased, during an adiabatic change.

DISCUSSION.

Mr. George Richmond.—The occasion is so opportune that I cannot refrain from pointing out what seems to me the peculiar adaptability of the $T\varphi$ diagram to the representation of the facts brought out in this paper.

Accepting as the definition of specific heat that it is the differential coefficient $\left(\frac{dH}{dt}\right)_m$ (m defining the circumstances under which heat is added—and which really defines it better than any number of phrases)—then it would seem that the geometrical illustration of this ratio on a diagram where dH is represented by the area included between two curves continued to infinity lacks the important element of simplicity.

On the $T\varphi$ diagram it is the area swept out by an ordinate travelling along a curve representing the conditions under which the ratio is taken, and the ultimate value of this ratio is the subtangent to the curve. The fact that its sign follows that of the tangent is thus self-evident.

Morever, the results arrived at through equations (8), (9), (10), and (11) can be represented directly on the diagram and deduced immediately therefrom. From the diagram [equation (51) of article, "Notes on Refrigeration"],

$$c_w = T\frac{d\varphi}{dt} + c.$$

From equation (10), $\varphi = \frac{L}{T} = \frac{a}{T} + b$;

$$\therefore c_w = -\frac{a}{T} + c,$$

which is equation (15).

If the curve is one cutting φ in the ratio $\varkappa : 1$,

$$c_w = T\frac{d(\varkappa\varphi)}{dt} + c = -\frac{a\varkappa}{T} + c,$$

which is equation (12); if $\varkappa$ be constant, and if it be a function of T, then,

$$c' = -\frac{a\varkappa}{T} + T\varphi\frac{d\varkappa}{dt} + c = -\frac{a\varkappa}{T} + L\frac{du}{dt} + c.$$

In estimating the relative value of different methods of deduction we must have in view—not the professor of thermodynamics, to whom the various complex equations are as familiar as the binomial theorem, nor even the student, but the busy professional man who has left college ten or twenty years. How many such men could reproduce, at a moment's notice, from fundamental principles, and without consulting a text-book, equations (8) and (9)? How many, on the other hand, if at any time familiar with the $T\varphi$ diagram, would fail to deduce from it the desired results? Moreover, the exact result looked for would be reached without the work necessary for a general solution, which may have little or no interest.

No one understands better than Professor Wood the value of graphical representation of analytical relations as a check upon the tendency to conjure with symbols, and he has laid students of thermodynamics under great obligations by his work in this direction. I do not fear, therefore, that my remarks will be misunderstood; the real point at issue is this: since we are certain that the subject of specific heat has been presented in the simplest and most elegant form of which the orthodox method is susceptible—while we are not sure the $T\varphi$ method has received full justice—should the latter, nevertheless, seem better adapted to the purpose, the conclusion is inevitable that the possibilities, in the way of simplification of this method, are worthy of careful investigation.

DIX.*

NEW PROCESS OF CUTTING CAMS.

BY S. [illegible], [illegible], JR.,
Member of the Society.

THE writer of this paper is engaged in the work of designing small and intricate machinery for the manufacture of parts of watches, and in the course of his experience found it necessary to produce cams of greater accuracy than could be obtained in old and well-known ways. As a result of this the following method of laying out and cutting such cams was devised by the writer, and is made the subject of this paper.

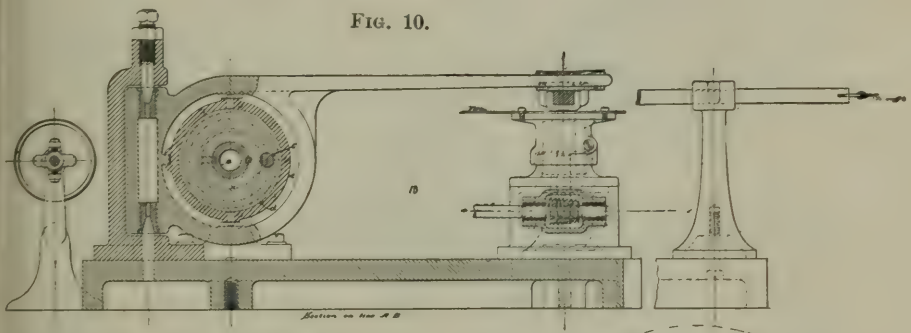
The following is a description of the cam cutting machines and manner of laying out the forms used therein. It is hoped that the diagrams that form part of this paper will give the reader a clear idea of the scheme.

To commence with, a chart of all the cam motions in a machine is laid out, similar to a sample diagram shown at Fig. 11, and a position line is drawn across it. From this chart the forms for the cam cutting machines are made. Figs. 12 and 13 were laid out from the chart at Fig. 11. The position line is located on them in its proper place, so that when the form is in the machine the line can be marked on the cams after being cut. The use of this line makes it possible to place all cams in a machine in their proper place at once. The line is marked on the cams from the form while in the machine, after the cam has been cut. A pointer is put in place of the cutter, and another pointer in the place of the roll acted on by the form. Figs. 8 and 9. When the position line marked on the form is brought around to the pointer at that place, the pointer in place of the cutter is made to mark a line on the cam. When all the lines marked on the cams in a machine are in line parallel with the cam shaft, they are ready to be secured to

* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

it. It will be noticed by referring to the drawings of the machines that the levers transmitting motion from the form to the cutter are multiplying. And in this case it is five to one, and the form, of course, must have a rise or throw five times that of the cam being cut. This is done so that errors of workmanship in making the form will be reduced in the cam, and more perfect work produced.

FIG. 10.



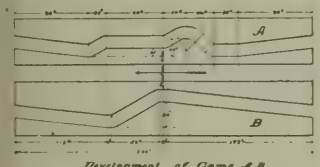


FIG. 11.

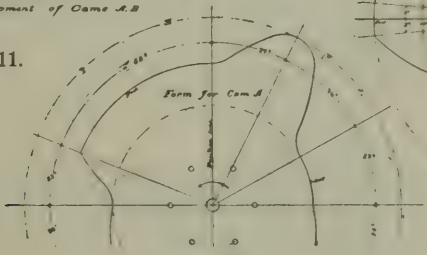


FIG. 12.

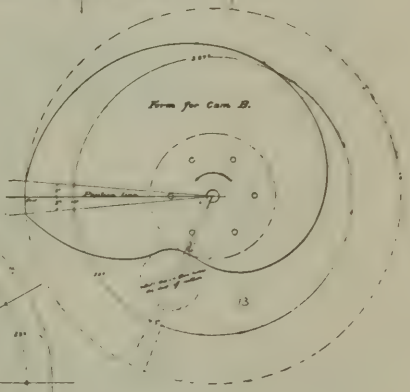


FIG. 13.

In some cases the form is laid out on a board covered with paper, and is then sawed out, taking care not to run over the line. It is then trued up with a file, and is ready to use in the cam-cutting machine. But in cases where great accuracy is necessary, the form is laid out on sheet brass about $\frac{1}{16}$ inch in thickness, and as metal will keep its form unchanged for any length of time, a cam can be reproduced the same as the original at any time.

An instrument to facilitate the laying out of forms on metal is shown by Figs. 16 and 17. It consists of an ordinary tubular beam compass, with strong points to scratch a plain line on the metal, and an attachment at the adjusting end that will enable it to be set to $\frac{1}{1000}$ of an inch of any required distance. The large sectional view, Fig. 17, shows the construction of the

FIG. 8.

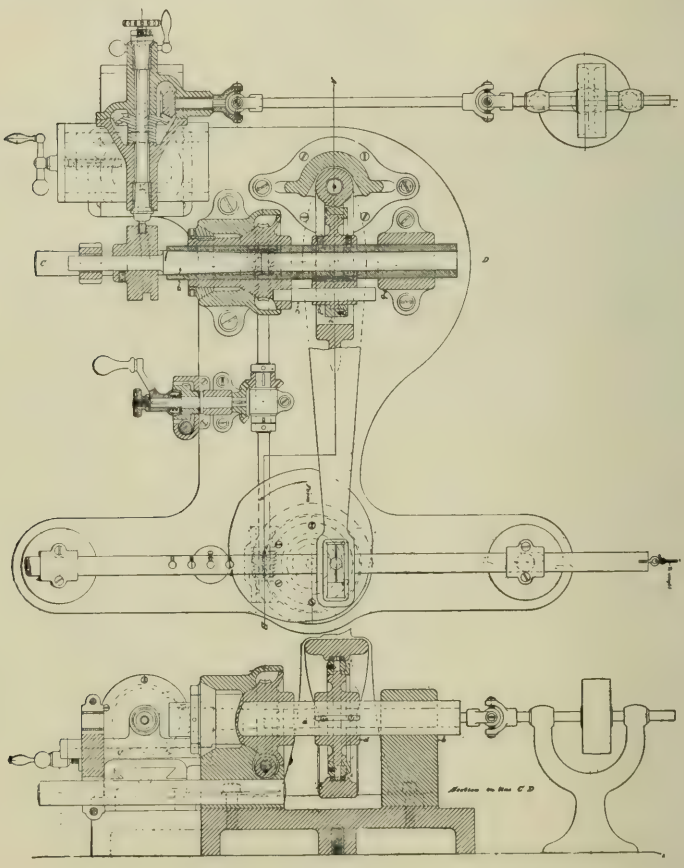


FIG 9.

adjusting nut. A steel scale with inches, tenths, and hundredths on it is used in connection with the compass. To operate it the point on the sliding head is run out to nearly the distance required, and the points are set in the divisions on the scale. A magnifying glass is used to see that the points rest in the center of the lines, the adjusting nut being used to bring that about. The part of the nut carrying the divisions can be turned inde-

pendently of it. It is then set to zero, and if the distance calls for several one-thousandths of an inch, more or less, it can be obtained by turning the nut in the right direction. The compass is then set ready to mark a line on the form.

The sheet metal on which the form is laid out is first prepared by drilling a hole near its center, the size of the center pin in the spindle on which the form turns in the machine. The hole is then filled with a small brass plug, having a fine center point in it. This insures the hole being in the right place when the form is finished. After the form is outlined on the brass plate it is sawed out with a band saw for metal, and is then placed

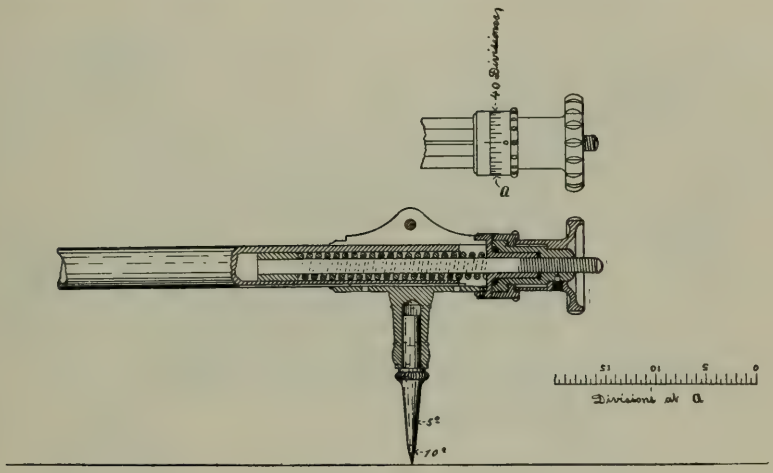


FIG. 16.

upon a small table and finished with a file. A fixture is attached to the table for holding the file perpendicular to the edge of the form. It is then ready to be put in the cam-cutting machine.

I will now proceed to describe the machine that cuts a groove in the side or face of a cam.

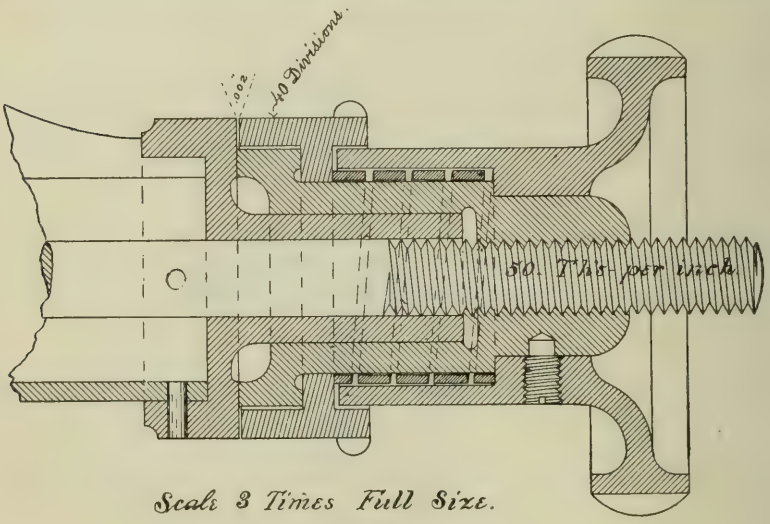
This machine is shown by Figs. 6 and 7, and consists of a strong bed-plate, on which are placed two upright spindles, to carry the cam to be cut and the form. Over them, and pivoted at one end, is a strong lever, so placed as to make a proportion of five to one between the cam and form.

At one end is a roll to act on the form. Over the cam spindle is the cutter spindle, with its driving gears. Adjustment is

provided up and down. The cutter spindle is driven through bevel gearing by a counter shaft and universal couplings. This allows for all necessary movements of lever and cutter.

Both cam and form spindles are turned by worm gears with the same number of teeth in each, and are turned in the same direction by worms which are made tapering, so that side shake can be taken up.

The worm shaft can be turned either by hand or power, as is clearly shown by the drawings. The form for this machine must be just the shape of the space inclosed by the groove in the cam, and must be five times actual size. This is necessary



Scale 3 Times Full Size.

FIG. 17.

on account of the roll and cutter being mounted on the lever. The roll should be just five times the size of the finishing cutter. A small slide in the end of the lever, marked (*a*) on plan Fig. 7, provides adjustment so that the sides of the groove can be finished with a fine chip, or trimmed up after being worn so badly as to require it.

The lever carrying the cutter and roll is held up to the form by a weight suspended at the end of a cord, which passes over a pulley swiveling at the top of a column, and attached to lever, as shown on plan Fig. 7. It can be seen that the machine just described is quite simple and will do excellent work.

The machine for cutting a groove in a cylinder cam, shown

in Figs. 8 to 11, is more complex, but will do work as perfect as the former. In this machine the cam, being cut, is moved endwise by the form as it turns, and whatever shape the form has is given to the cam, as perfectly as in the other machine. The roll acted on by the form is carried by a bar, which moves

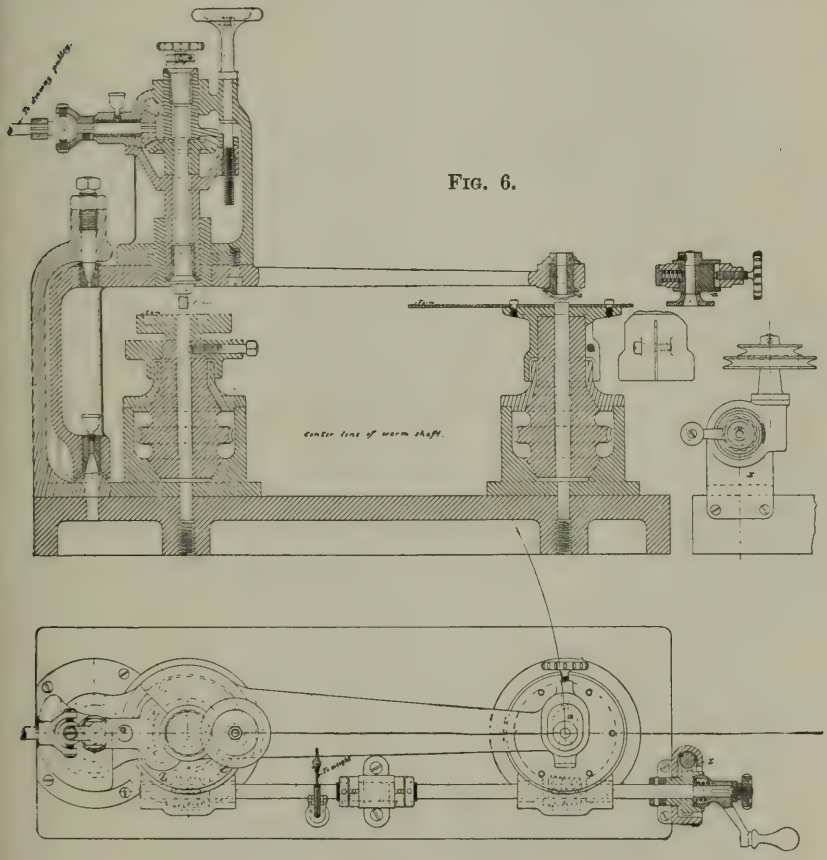


FIG. 6.

FIG. 7.

parallel with the spindle carrying the cam to be cut. Motion is transmitted from the bar to the cam spindle by a lever, which is pivoted so as to give the same proportion of movement as in the former machine. The worm shaft can be turned by hand or power. Means are provided to take up any side shake between worm and gear. The cutter and its driving gears are mounted on a compound slide, so that it can be adjusted to position with

ease. A support is provided for the outer end of arbor carrying the cam, to prevent chattering when taking heavy cuts.

The spindle (*a*) is free to move endwise in the outer spindle, of which the worm gear is a part, and also in the back bearing (*b*). The driving pin (*c*) is fast in the worm gear spindle ; and passes freely through a disk (*d*), which is keyed fast to the sliding spindle (*a*). A ring (*e*) which cannot turn encircles the disk (*d*), and in it are pins pivoted in small slides in the lever. Adjustment is provided to take up any shake in pins or slides. This arrangement is necessary on account of the foreshortening of the lever. In this machine it is not necessary to have the form just five times the size of the space inclosed by the groove, as in the former machine ; but the rise or throw must be. The form ought to be as large as convenient in order to avoid having too steep a rise for the roll to overcome. A number of holes are provided in the bar carrying the roll, to assist in adjusting it properly. A weight at the end of a cord, attached to the bar, keeps the roll up to the form while cutting the cam. Means are provided to enable the form to be turned independently of the spindle. This is useful in starting to cut the cam. A hole is first drilled in the cam blank, to start the cut. The hole is brought opposite to the cutter by turning the blank on its spindle, then the form is turned to adjust endwise. The machine is then set ready to cut the cam. The position line is marked on the cam after being cut, to avoid any chance of error from its slipping on the arbor.

In many cases the pin working in the groove of a cam is secured in the end of a lever working on a fulcrum. If the radius of the lever be short, and the throw of the cam be great, a serious cramping of the pin may take place, on account of the foreshortening of the lever. On Figs. 14 and 15 is shown a way whereby the cutter may be moved in cutting the groove in a cam, in the same way that the pin itself would move, on account of the foreshortening of the lever. In order to simplify this problem, the pin should not work below the center line of the cam. To set this device the cam blank and form should be turned to exactly the center of the throw, and then, with the rock-shaft (*a*) in the position shown, the adjustable arms (*bb*), Figs. 14 and 15, are moved up to contact with the blank, one on each side. The bar (*d*), on which arms (*bb*) slide, is supported at each end by yokes (*cc*) which in turn slide on round bars (*ee*).

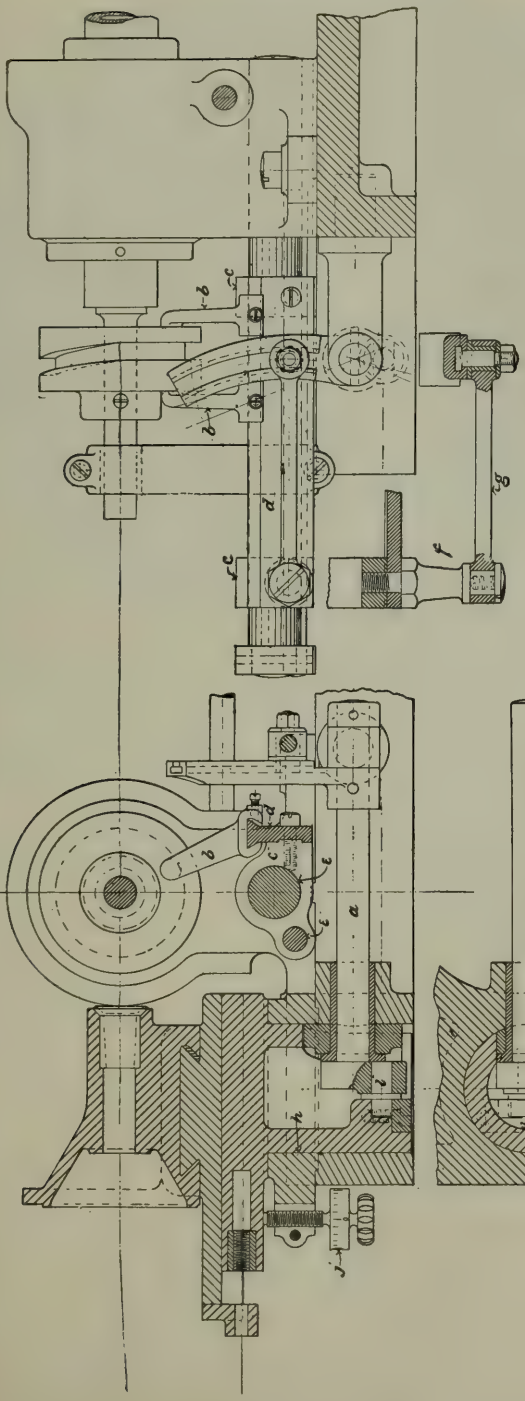


FIG. 15.

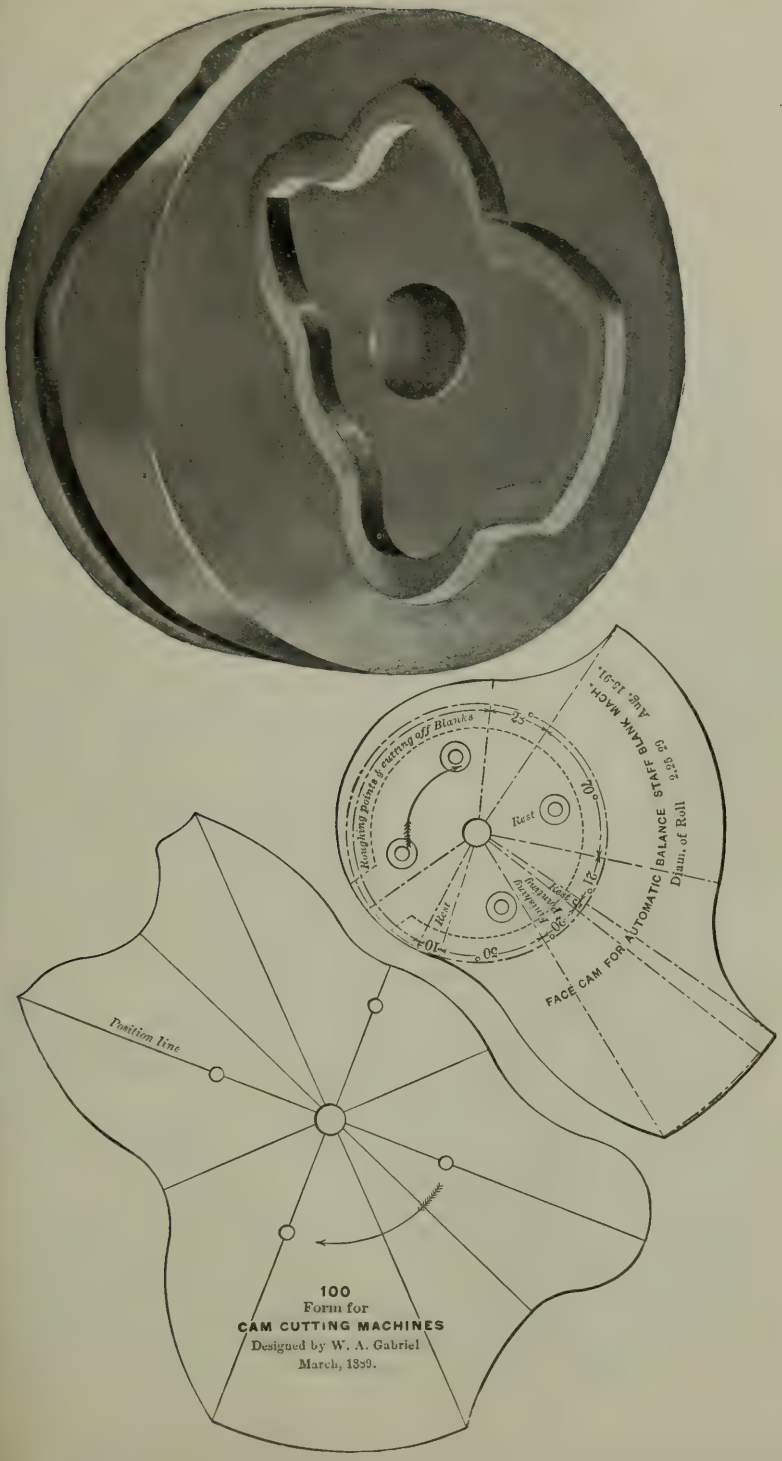
FIG. 14.

At the outer end of bar (*d*) is a stud (*f*) to which is pivoted a connecting rod (*g*). One end of this rod is adjustable in a slot in a curved arm which is pinned fast to the rock-shaft (*a*). At the opposite end of the rock-shaft, and within the vertical slide (*h*), is a short rocker arm carrying a flatted pin (*i*) which slides in a suitable slot in slide (*h*). As the cam is being cut, its movement endwise causes motion to be imparted to the mechanism just described; and that in turn causes the vertical slide (*h*), carrying the compound slides and cutter spindle, to move up and down. In order that the amount of motion up and down shall equal the foreshortening of the lever and pin which is to work in the cam, it is first found by measurement of the drawings of the machine in which the cam is to work. Then, by means of a micrometer screw at (*j*), and the adjustment of the connecting rod in the slot in the curved lever, the machine is set to an equal amount, and then is ready to cut the cam.

The writer of this paper does not think that, practically, this foreshortening of a pin working in a cam cuts much of a figure, as in most cases it can be corrected by rounding the pin a little. But some might think it ought to be provided for in a cam-cutting machine, and for this reason the writer thought best to describe a way by which this objection might be overcome.

Two machines, on the principle of those described in this paper, have been in successful operation for the past three years, which produce work giving entire satisfaction.

It would be a source of pleasure to the writer of this paper if anything in this method of cutting cams should be of use to any member of this Society.



100
Form for
CAM CUTTING MACHINES
Designed by W. A. Gabriel
March, 1889.

DX.*

AN ANALYSIS OF THE SHAFT GOVERNOR.

BY F. M. RITES, PITTSBURGH, PA.

(Member of the Society.)

CONSIDERING the amount of labor which has been spent upon the theory and method of steam distribution and the mechanical design of steam engines, it is strange that so little work has been done towards perfecting the governor.

While the subject of the steam engine proper is certainly an interesting one, that of the governor is not less so; yet technical literature shows no lack of treatment of the former, to a practically complete exclusion of more than a mere reference to the latter. It is true that the patent records are proof of a reasonable activity on the part of inventors in this subordinate branch of steam engineering; but the claims for novelty have almost invariably been restricted to structural features rather than indicative of radical departures from the original design of 1839.

However, disregarding the mechanical improvements, it is a fact that not a single complete work of such a character, either of description or of a scientific nature, has ever been issued. A credible explanation of this condition is that the average consumer does not fully realize the importance of the subject, and the manufacturer does not care to part with the information which it has cost him dearly to acquire; while there is a curious want of comprehension among scientists as to the requirements and possibilities of shaft governing. It is to clear up the general uncertainty, awaken a well-deserved interest, and indicate the splendid opportunity for research in a practically unexplored mechanical field, that this paper is presented.

With the advent and development of the electric industries has grown a demand, continually more exacting, for better service from this hitherto much neglected mechanism; but it should

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be noted, however, that competition among manufacturers in general has been confined to the question of the degree of regulation, and that, with a few exceptional cases, the subject of rapidity of adjustment has been regarded in silence, so that even yet the importance of this function of a governor as a factor in the service of a power plant is not sufficiently appreciated.

On account of the peculiar duty imposed upon the engines of an incandescent electric light plant, in which those already partially loaded must receive occasional considerable accessions of power, the ability of the governor to "catch the load" is especially valuable in a commercial sense in preventing momentary variations of voltage and consequent fluctuation in the lights. On the contrary, the effect of a sluggish governor is especially annoying to both producer and consumer, and the evil is more apparent during the period of greatest capacity, when the increasing load is continually shifted and returned to the engines in operation, and the entire plant with its output is more or less influenced, to its detriment.

In the same manner, but in far greater degree, the entire equipment of an electric railway is reliable and durable, other things being equal, in proportion to the power of the governor to meet continual and instantaneous changes of load over wide ranges without surging or permitting a variation of speed greater than the legitimate amount of the regulation, while the character of the service resultant from a governor retarded in its action gives every indication of its uneasy search for a position of stability which continually eludes it, but which it passes and repasses without finding. In this most recent industry the governor also first appears prominently as a factor in the economy of the engine.

If the governor be not equally prompt to adjust for the new position corresponding to a violent change of load, a vibratory action or a racing effect may very easily be generated, which shall cause the reverse of an economical distribution of the steam. In such a case the steam consumption approaches more or less closely the limits represented by the extremes of cut-off. The evil is, of course, more marked in the case of multiple-expansion engines, where the range of economy is greater, so that an imperfect governor often condemns by association an engine of highly efficient steam distribution, when regulated to suit the

load, although the loss is not so great with engines whose efficiency remains more nearly uniform over their range of power.

Even though the actual variation of the load may be an insignificant amount, and the corresponding change of speed be imperceptible, or the real change in speed not beyond the limits of the regulation, so that the average revolutions per minute as read over an extended period of time are perfectly normal; yet the average efficiency of the steam distribution may be far from the efficiency of the average and perhaps perfectly proper steam distribution.

There is no intention to detract from the value of a well-regulated governor, but it is a certain fact that rapidity of regulation should hold a far more important position in its influence on the constancy of both speed and economy. The two terms "degree of regulation" and "rapidity of regulation" are often confounded and misapplied, but the properties of the governor they represent are so distinct that they may be varied independently even in the same governor. The degree of regulation may be defined as the percentage of variation of speed necessary to maintain a unity between the centrifugal and centripetal forces in governor adjustments, corresponding to variations of load or steam pressure. The rapidity of regulation implies its own definition as the speed of adjustment to meet the varying conditions of load or steam pressure. The degree of regulation depends on the rate of variation of the centrifugal force at constant speed with respect to that of spring tension; while the rapidity of regulation depends on the effect of the inertia of the masses that compose the governor.

The degree of regulation is a variation of speed as measured over a considerable interval of time, during which the adjustment of the governor is maintained constant; while the rapidity of regulation deals only with momentary demands upon the governor.

It is perfectly possible to adjust the relation between the centrifugal force and that of the spring to such refinement that perfect isochronism is attained, and yet be so slow of adjustment as to possess no stability even under moderate changes of load, and the resultant racing will be even more violent with a supersensitive regulation.

On the other hand, a governor may be designed to utilize its

entire inertia for *rapid* regulation, without the power to do so on account of the low *degree* of regulation, so that a governor perfectly designed with respect to its inertia effect will not alone guarantee good regulation, nor does close regulation necessarily imply rapidity of adjustment; on the contrary, it is perfectly possible in a poorly designed governor to oppose the increment of centrifugal force by that of inertia; and for the same reason (opposition to the effect of inertia) the many ingenious devices for increasing the possible degree of regulation are of doubtful utility, by acting as obstructions to a rapid adjustment.

The problem of inertia becomes still more complicated by the necessity of distinguishing between the effect of moment of inertia of the weights considered concentrated at their center of gravity, and hereafter to be termed "tangential inertia," and that due to the aggregation of moments of inertia, caused by angular acceleration about the center of support of the particles composing the mass of the weights, and hereafter to be termed "angular inertia."

The action of these two forces of inertia are here distinguished and described probably for the first time, and it is of the utmost importance that they should be thoroughly understood, to be fully appreciated in their application as governor forces. They are both of inertia origin, but the first is generated by the momentary tangential effect about the center of revolution of the shaft, and the other by a varying angular velocity about its center of support and rotation. In other words, the one is a moment of inertia of the concentrated mass about its center of revolution reduced to a secondary moment about its center of rotation and support. The other exists only as a primary moment about its center of support. Again, these may assist or oppose each other, or together unite with or in opposition to centrifugal force. In short, it is possible to ring all the changes of combination of the three forces according to the design of the governor.

Mathematically, it is possible to combine the two inertia forces in their effect on rotating the weight about its own center into one force applicable at the center of oscillation, located with reference to the center of revolution, and which is resisted by the moment of inertia of the weight with reference to its own center of support.

If mr_1^2 be the moment of inertia about the center of revolution where r_1 is the radius of gyration (see Fig. 18), then $\frac{mr_1^2}{r_2}$ is the corresponding inertia force exerted at the center of oscillation, where r_2 is the radius of oscillation, and $\frac{mr_1^2}{r_2}r_3$ is the moment of this inertia about the weight's supporting pin to produce angular movement, where r_3 is the distance of the center of oscillation as referred to the center of revolution,

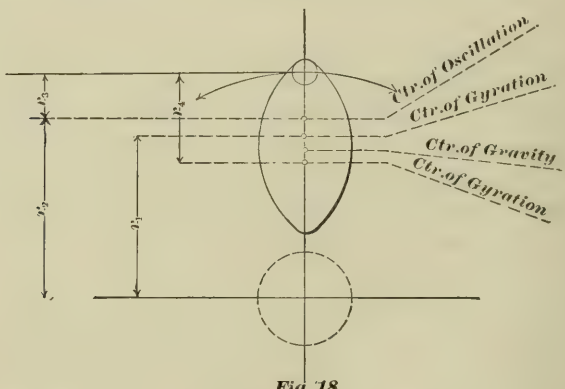


Fig. 18.

while mr_4^2 represents the moment of inertia of resistance to rotation about the supporting pin where r_4 is its radius of gyration about this pin; so that the ratio

$$\frac{mr_1^2r_3}{mr_4^2r_2} = \frac{r_1^2r_3}{r_4^2r_2}$$

is the effect in angular displacement about the supporting pin due to an angular acceleration about the center of revolution, and is independent of the mass of the weight.

If $r_3 = 0$, then $\frac{r_1^2r_3}{r_4^2r_2} = 0$, and the supporting pin is either identical with the center of oscillation or situated on the normal to the radius of oscillation through that point, and there is no inertia effect, but the governor has reverted to a purely centrifugal type.

It is desirable here to find relatively exact terms to represent the forces of tangential and angular inertia.

Referring to Fig. 18 again, let x = the radius of gyration of the weight about its center of gravity, y = the distance of the center of gravity from the center of the shaft, and $z = a - y$ = the distance of the center of gravity from the center of the supporting pin.

The demonstration may be found in any advanced treatise on mechanics that

$$Mr_1^2 = My^2 + Mx^2 \quad \therefore r_1^2 = y^2 + x^2$$

$$Mr_4^2 = Mz^2 + Mx^2 \quad \therefore r_4^2 = z^2 + x^2$$

$$r_2 = \frac{r_1^2}{y} = \frac{y^2 + x^2}{y}$$

$$r_3 = a - r_2 = \frac{ay - y^2 - x^2}{y}$$

$$\frac{Mr_1^2 r_3}{Mr_4^2 r_2} = \frac{y^2 + x^2}{z^2 + x^2} \times \frac{ay - y^2 - x^2}{y} \times \frac{y}{y^2 + x^2}$$

$$= \frac{y(a - y) - x^2}{z^2 + x^2} = \frac{yz - x^2}{z^2 + x^2}$$

$$= \frac{Myz - Mx^2}{Mz^2 + Mx^2}$$

From this it appears that Myz is the tangential inertia My reduced to a moment about the supporting pin, and Mx^2 is the angular inertia, which in this case is a negative moment about the same point. Again removing the factor M for purposes of convenience, and differentiating successively with respect to x, y, and z, and equating each result to 0, then solving for the variable quantities as follows :

$$\frac{d}{dx}\frac{yz - x^2}{z^2 + x^2} = \frac{-2x(z^2 + x^2) - 2x(yz - x^2)}{(z^2 + x^2)^2} = 0$$

$$-2x(z^2 + yz) = 0$$

$$x = 0$$

$$\frac{d}{dz}\frac{yz - x^2}{z^2 + x^2} = \frac{d}{dz}\frac{(a - z)\,z - x^2}{z^2 + x^2} = 0$$

$$\frac{a\,(z^2 + x^2) - 2z\,(az - x^2)}{(z^2 + x^2)^2} - \frac{2z\,(z^2 + x^2) - 2z^3}{(z^2 + x^2)^2} = 0$$

$$z = x$$

$$\frac{d}{dy}\frac{yz - x^2}{z^2 + x^2} = \frac{d}{dy}\frac{(a - y)\,y - x^2}{(a - y)^2 + x^2} = 0$$

$$a^2 - 2ay + y^2 = x^2$$

$$y = a \pm x$$

A second testing differentiation of each of these primary results shows that the quantity

$$\frac{Mr_1^2 r}{Mr_4^2 r_2} = \frac{yz - x^2}{z^2 + x^2}$$

is a maximum when x and z approach 0 and y approaches a.

The investigation might easily be checked at the point of the differential with respect to x, for if $x = 0$

then $$r_1 = r_2 = y \text{ and } r_3 = r_4 = z,$$

and $$\frac{Mr_1^2 r_3}{Mr_4^2 r_2} = \frac{r_1}{r_4} = \frac{r_2}{r_3} = \frac{y}{z}$$

while the efficiency of such an arrangement of centers with a concentration of the mass increases as the mechanical centers approach the weight pin.

In the same manner the formula

$$\frac{Mr_1^2 r_3}{Mr_4^2 r_2} = \frac{yz - x^2}{z^2 + x^2} \qquad \text{becomes}$$

$$\frac{Mr_1^2 r_3}{Mr_4^2 r} = \frac{yz + x^2}{z^2 + x^2} = \frac{y^2 - ay + x^2}{z^2 + x^2},$$

and

$$\frac{Mr_1^2 r_3}{Mr_4^2 r_2} = \frac{yz + x^2}{z^2 + x^2} = \frac{y^2 + ay + x^2}{z^2 + x^2}$$

in the other two possible modifications where the center of gravity falls without the space between the centers of support and revolution.

The efficiency increases in both these cases as x grows greater and z grows less, but in the former as y approaches a, and the latter as y approaches $-a$, so that a maximum efficiency of the last arrangement of centers is impossible until y has passed through infinity and the whole plan has reverted to the preceding one. The investigation is, therefore, confined to a consideration of but two designs, and these merge into each other.

It may be urged in criticism that no account whatever has been taken of the influence of centrifugal force in effecting adjustment, and that it has been restricted to the office of determining the degree of regulation. The slight is intentional, and additional advantage is taken of this opportunity to insist that in the perfect governor centrifugal force should be reduced to a minimum while that of inertia assumes the position of approximately the sole adjusting force for changes of load and steam pressure.

It will be necessary to allude still further to the comparative action of all these forces as influenced by the relative location of their centers of support and application of force; but, as a preliminary to the further investigation of the properties of governors, it will be necessary to understand the relations between Speed of Engine, Permissible Variation of Angular Velocity, Weight of Fly Wheel, Time of Governor Adjustment.

A familiar form of fly wheel formula is

$$Wt. = \frac{C \,.\, H.P.}{R^2 \, D.},$$

where

Wt is the weight of rim,
C is a constant,
R is revolutions per minute,
D is diameter of rim in feet.

It is, however, only approximately correct, and wholly misleading as to the relative values of the variable quantities.

Another is

$$Wt. = \frac{C \,.\, AP}{f \, R^2 \, D^2},$$

where AP represents cylinder capacity, and f is a secondary constant.

This is fundamentally proper, but is insufficient because of the form in which the variable quantities appear; so that it is advisable to evolve a wholly new formula which will be accurate and available.

The excess of power in the fraction of a revolution must be equal to the energy due to increase of velocity of the fly wheel in that time; hence, as

$$\frac{33000\ H.P.}{R}$$

is the foot pounds of work in one revolution, and

$$\frac{33000\ H.P.}{R}x$$

is the excess of energy during a portion of the stroke, which tends to increase the velocity of the fly wheel, but which is unnecessary in positive value for this purpose; and as

$$M\left(\frac{c^2 - v^2}{2}\right)$$

is the energy of increase of velocity of fly wheel, corresponding to the excess of power; or, in other words, is the result of the sum of the tangential forces in excess of the opposing ones, and is the work absorbed by the fly wheel for service as kinetic energy during subsequent retardation; therefore,

$$\frac{33000\ H.P.}{R}x = m\left(\frac{c^2 - v^2}{2}\right). \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let $\frac{c - v}{v} = b = \%$ variation of speed $c = v\,(b+1)$. . . . (2)

$$\frac{33000\ H.P.}{R}x = \frac{Wt.}{64.4}(v^2\,[b+1]^2 - v^2) = \frac{Wt.\ v^2}{64.4}(b^2 + 2\,b). \quad (3)$$

but $v = 3.14\ D\ \frac{R}{60}$, and assuming for x a value $x = \frac{1}{8}$, and solving for $Wt.$,

$$Wt. = \frac{C.\ H.P.}{R^3\ D^2},$$

and the weight of the rim per horse-power is

$$Wt. = \frac{C}{R^3 D^2},$$

where C is the combination of all the numerical quantities, and varies from 10,000,000,000 to 20,000,000,000.

Substituting for $Wt.$ in equation (3), and giving x the same value ($x = \frac{1}{3}$), we have

$$\frac{33000 \text{ H.P.}}{8\,R} = \frac{(3.14)^2\, C(b^2 + 2\,b)\, R^2\, D^2}{64.4 \times 3600 \times R^3\, D^2}\, 2$$

$$b^2 + 2\,b = .0048$$

$$b = .0023 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

From the equation

$$\frac{Mv^2}{2} = \frac{Wt.}{64.4}\,\frac{3.14^2 D^2 R^2}{3600}$$

$$= \frac{CHP\,(3.14)^2 D^2 R^2}{R^3 D^2 \times 64.4 \times 3600}$$

$$= \frac{850000\ H.P.}{R}$$

$$\text{Fly wheel energy per H.P.} = \frac{850000}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Properly interpreted, these formulæ are full of interesting information.

It will appear from (4) that the weight of the fly wheel should vary inversely with the cube of the revolutions and the square of the diameter, which is the true relation between these quantities.

Referring to (5), the limit of variation of speed with such a weight of wheel from excess of power per fraction of revolution is less than .0023.

Equation (6) gives the rate of reduction of total energy in the wheel, due to velocity, as the speed increases, and incidentally shows the advantage of high speed in the ability to stop and start quickly, and the proportional inability to do damage in case of accident.

If in (3) is substituted for b the value .02, which is generally

acknowledged as acceptable service for degree of regulation of a governor, and the equation solved for x thus:

$$\frac{33000\ H.P.}{R}\ x = \frac{(3.14)^2 D^2 R^2 CH.P.}{R^3 D^2 \times 64.4 \times 3600}\ .0404$$

Then $x^1 = 1.04$ is the number of revolutions necessary to increase the speed of the fly wheel two (2%) per cent. with no resistance to the full power of the engine during that time, except that of the fly wheel.

If the steam distribution were perfectly controlled over the time of this change of speed, so as to correspond to each increment, then the average effective power will be one-half the full amount, and the time required to make the change of .02 will be increased to double, or the time required to make 2.08 revolutions of the engine; and the real problem of governor design is to effect a rapidity of adjustment over the whole range of the governor, during the time required to accomplish 2.08 revolutions of the fly wheel.

A lighter fly wheel than that indicated will allow less time for adjustment, but except for this single possible correction the figures are positive; and a governor is proportionally far from perfection that requires over 2.08 revolutions to adjust through extreme positions under an instantaneous change of its entire rated load.

However, as the force of inertia is a variable amount, and dependent on the angular acceleration of the fly wheel in the perfect governor, the actual speed of adjustment will vary with the weight of the rim.

The constant appearance in these formulæ of an isolated R may be explained by the fact that the disturbing element of excess of power per revolution becomes proportionally less as the speed increases, and its presence further indicates that even with a purely centrifugal governor the time of regulation will decrease inversely with the speed, although not proportionally, but will, however, be more liable to surge in the higher speeds without the co-operation of the inertia forces.

In the following figures only the elementary single weight is shown, and for the purpose of convenience in the analysis of the adjusting forces, is supposed to be balanced for gravity. The eccentric is not shown at all, and may be assumed to be prop-

erly operated upon by the movement of the weight through a convenient connection.

Fig. 19 illustrates probably the most common form of distribution of centers of support and movement where the evident intention is to use the greatest leverage of the centrifugal force. As a matter of fact, centrifugal force is the only element that is utilized for adjustment, since the tangential inertia is directly resisted by the supporting pin and is thereby rendered inoperative. In Fig. 19 the area is so small compared to its thickness

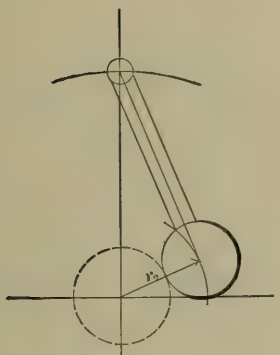


Fig. 19.

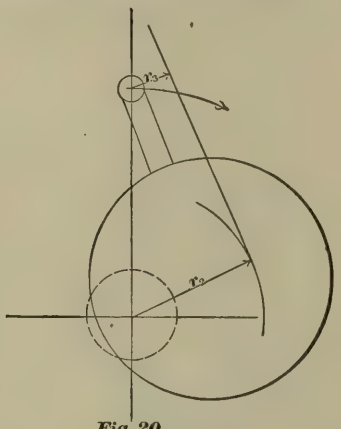


Fig. 20.

that the centers of gravity, gyration and oscillation are practically identical and r_3 is substantially equal to zero by the arrangement, and the expression

$$\frac{mr_1^2 r_3}{mr_4^2 r_2} = 0,$$

so that this is a form more or less nearly approaching the type of the pure centrifugal governor.

This is true whether the figure illustrate right or left hand rotation.

Fig. 20 illustrates a method of improving the action of this governor without changing the center of gravity of the weight or the resulting moment of centrifugal force. The elements of composition are so far removed from the center of gravity that their angular acceleration about the pin (P) becomes prominent; but, to be effective, it is possible to run the engine in left-hand

rotation only—otherwise, the new force becomes negative in effecting adjustment. r_3 is made positive, and all the radii except that of center of gravity are increased.

In Fig. 21 still another form is shown, and here the moment of the inertia of the weight becomes a prominent force, uniting with that of centrifugal with the engine in right-hand rotation, but opposing it in left-hand rotation.

In Fig. 22, with the same distribution of material in Fig. 20 as in Fig. 19, there is still greater complication, for in this case both tangential inertia and angular inertia work in harmony in

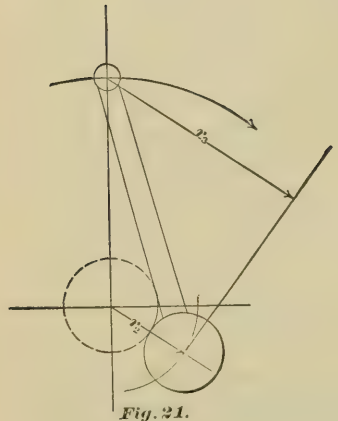


Fig. 21.

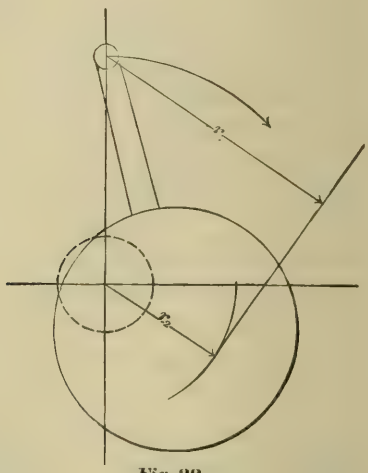


Fig. 22.

either condition to oppose or assist centrifugal force according to the direction of rotation.

Fig. 23 is still another possible modification, reversing the action of inertia, rendering it necessary that the governor be operated through left-hand rotation in order that the two forces unite in their action.

In Fig. 24, showing a redisposition of the particles about the center of gravity as shown in Fig. 23, to correspond with Figs. 20 and 22, the influence of the three forces becomes still more intricate, since, under a left-hand rotation, centrifugal force and that of tangential inertia unite in opposition to angular inertia, while with a right-hand rotation centrifugal force and angular inertia join against tangential inertia. In this figure, the angu-

lar inertia has been purposely arranged to illustrate a perfect balance between it and the tangential inertia, leaving centrifugal force alone operative.

Fig. 25 is a fair example of an intelligent distribution of centers to utilize in a measure all three forces, but the governor must be run in left-hand rotation or be subject to the disturbance of a conflict between them.

It might still further be slightly improved by increasing the effect of angular inertia.

In general, it may be stated that with a maintained constancy of moments of inertia of the weight about the two centers

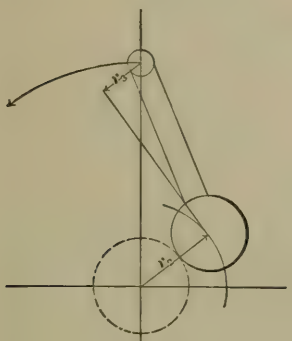


Fig. 23.

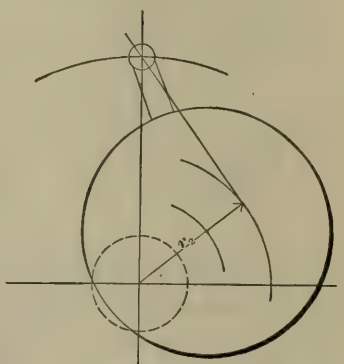


Fig. 24.

of support and revolution, the angular movement of the weight about its own center is proportional to the ratio $\frac{r_2}{r_3}$, and the actual angular movement is $\frac{r_2}{r_3}$ multiplied by the angular increment of advance of the fly wheel, and corrected for the assumed constant relation between the two moments of inertia of the weight.

In Fig. 19, r_3 is 0, and the force of inertia is ineffective, as we have already determined.

In Figs. 21 and 22, r_3 is much greater than is the case in Figs. 2 and 7, so that inertia is proportionally less useful, and the shape of the weight in Fig. 22 is advisable as permitting a more active adjusting force. On the contrary, in the form Fig. 23, r_2 may be made as large as desired, thus increasing the action of the force of tangential inertia, while the mass itself may be so

concentrated that its angular inertia in opposition may be insignificant.

From the foregoing it will be understood that in general the necessary time of regulation grows less in proportion :

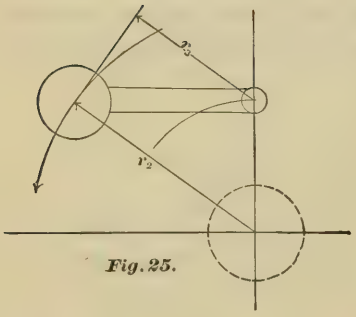


Fig. 25.

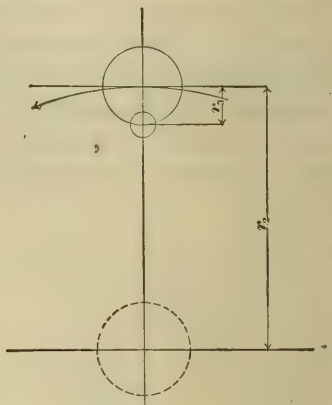


Fig. 26.

(1) As the lever arm of the weight grows shorter ;
(2) As both weight and pin are located further from the shaft ;
(3) As the speed of the engine increases ;
(4) As the fly wheel is made lighter ;

and that the perfect governor approaches the form in Fig. 26 (which, however, is extremely difficult of application) where centrifugal force becomes reduced to a minimum, while both the tangential and angular inertia of the weight reach a maximum and are co-operative with the centrifugal force, and where r_1 and r_3 become identical with r_2 and r_4 respectively, so that $\frac{r_2}{r_3}$ and $\frac{mr_1^2r_3}{mr_4^2r_2}$ both become a maximum.

To meet a possible doubt as to the efficiency of regulation attainable in the several forms that have been shown, the following demonstration is given :

In Fig. 27 let S represent the engine shaft about which the governor revolves, P the weight pin or center of motion of the weight, W, as it moves from the shaft under centrifugal force.

The axes of x and y intersect at P, and x and y are the ordinates of any particular position of the weight W.

The centrifugal force of the weight in any position is propor-

tional to its distance from the shaft, and the rotative effect is proportional to the product of this distance by the lever arm; therefore,

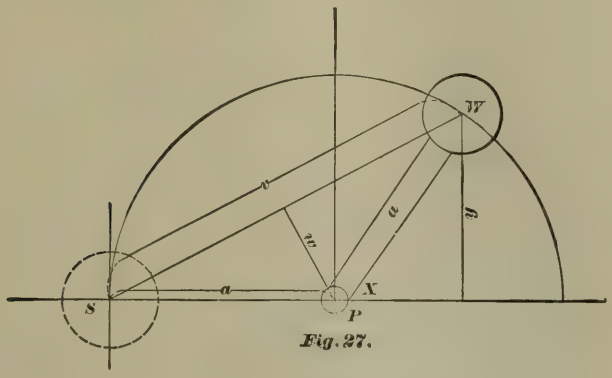


Fig. 27.

$$z = vw$$
$$z^2 = v^2w^2.$$

From the equation to the circle,

$$y^2 + x^2 = a^2$$
$$y^2 = a^2 - x^2.$$

From the figure,

$$v = (a + x)^2 + y^2$$
$$= (a + x)^2 + a^2 - x^2$$
$$= 2a^2 + 2ax$$
$$w^2 = a^2 - \left(\frac{v}{2}\right)^2$$
$$= a^2 - \frac{a^2 + ax}{2}$$
$$z^2 = v^2w^2$$
$$= a^2(a^2 - x^2).$$

Thus the rotative effort of the centrifugal force is variable, according to the formula

$$z^2 + a^2x^2 = a^4,$$

which, being of the second degree and symmetrical about both axes, brands it as representative of an elliptic form of curve.

Following the investigation still further, and selecting a general arrangement of the parts (Fig. 28), where the weight does

not start from the center of the engine shaft, but at a distance, b, to one side of it.

Then, as before,

$$
\begin{aligned}
z &= vw \\
z^2 &= v^2w^2 \\
y^2 + x^2 &= a^2 \\
y^2 &= a^2 - x^2 \\
v^2 &= (c + x)^2 + y^2 \\
&= c^2 + 2cx + a^2 \\
v &= m + w \\
m &= \sqrt{a^2 - w^2} \\
n &= \sqrt{c^2 - w^2} \\
v &= \sqrt{a^2 - w^2} + \sqrt{c^2 - w^2} \\
w^2 &= 4a^2v^2 - c^4 + a^4 + v^4 - 2a^2c^2 - 2c^2v^2 + 2a^2v^2 \\
z^2 &= v^2w^2 \\
&= a^2c^2 - c^2x^2 \\
z^2 + c^2x^2 &= a^2c^2,
\end{aligned}
$$

which is also of the second degree and symmetrical about both axes, indicating that the rotative effort reaches a maximum when

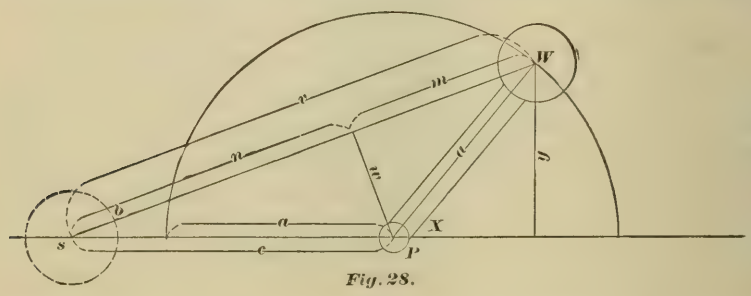


Fig. 28.

the weight is vertically over its pin, and decreases at the same rate as its former rate of increase.

If in equation (2), $c = a$, it becomes $z^2 + a^2x^2 = a^4$, which is identical with (1). The rate of variation in the case of (1) is

$$\frac{dz}{dx} = -a\frac{x}{\sqrt{a^2 - x^2}}$$

and in (2)

$$\frac{dz}{dx} = -c\frac{x}{\sqrt{a^2 - x^2}},$$

differing only by a constant factor; so that if, in Fig. 18, the mass of the weight should be varied proportionally with c, and the rotative force be cvw, there will be no difference of rate of variation and no difference in speed of engine, for the elliptic curve of variation of rotative force will be identical in the two instances shown. A similar result may be shown for any other relative location with a correspondingly varying mass in the weight.

From this it will be clear that as the curve representing rotative effort of centrifugal force is invariably a section of an ellipse, and as the curve of tangential effect of centripetal force can in the same manner be shown identical; and, further, that as the degree of regulation depends only on the relation these forces bear to one another, a properly variable opposition between them can always be designed, which shall yield the desired regulation.

It should also be noted that although, if the weight be variable radially along its lever arm, the regulation will not change, and even the speed may be kept constant by coincidently and proportionally changing the amount of the mass of the weight; yet the rapidity of adjustment will change for such a rearrangement of centers, as the center of oscillation is changed.

A special practical application of the principles that have been discussed, and the results in rapidity and quality of regulation, should prove interesting, and is shown in Fig. 29.

In this case the moment of centrifugal force is represented by the product of the line a by b, and the leverage of the force of inertia is similarly represented by the ratio of the lines d and c. Both of these moments unite in producing adjustment with left-hand rotation.

The ratio $\frac{r_2}{r_3}$ of Fig. 19 is here represented by the quotient $\frac{c}{d}$, which is sufficient to produce a powerful inertia effect for rapid regulation.

It is true the moment of the force due to angular acceleration is in opposition to those of inertia and centrifugal force, but in this particular instance the governor was designed to be inclosed in a case and entirely immersed in oil, which, besides acting as a lubricant, plays an important part in the governor adjustment through its angular inertia, by impact and friction on the weights, thus compensating for the loss of the corresponding force on the governor weight. The comparatively great angular displacement of the weight when at rest from the centre of centrifugal

force would indicate considerable initial tension on the springs; but, to neutralize this, the opposing centrifugal force of the eccentric and strap—which are made very heavy—moves the position of the ideal center of gravity of the combination much nearer the center of the shaft, and permits the use of short, heavy springs.

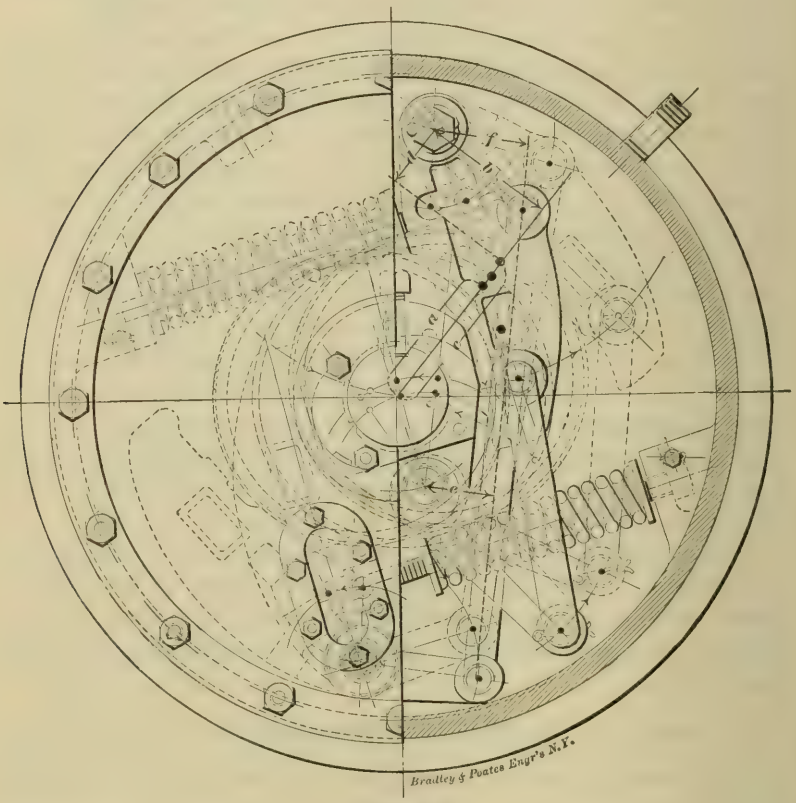


Fig. 29.

The ratio of the distances f and c is a measure of the ability of the governor to resist the reactionary forces of the reciprocating valve gear, which, being less with the shorter strokes of the earlier cut-off, allow this ratio to correspondingly vary so that the resisting strength of the governor is practically uniform over its range by means of the unequal varying leverages.

Again, the efficiency of inertia governing is properly expressed in terms of angular movement of the eccentric about its support-

ing pin, so the attachment from the extreme end of the weight to the eccentric results in the maximum adjustment of the eccentric.

On the whole, the design is compact, and with the addition of the exceptionally heavy eccentric is unusually strong, even for the limited space occupied. That its forces of adjustment are equally effective may be appreciated from the results of an expert test, where the entire rated load of the engine was instantaneously thrown on and off without changing the speed beyond the degree of the regulation. Continuous indicator cards during the change of load showed a complete adjustment in either direction in less than one second of time.

This article would be incomplete without mention of the effect of reactionary strains of reciprocating valve gear.

The formula for maximum inertia strain, as derived from that for centrifugal force, but neglecting the modifying influence of angularity of eccentric rod, is

$$F = .00002835\ R^2 r\ Wt,$$

where

F is the force required,

R is the revolutions per minute,

r is the eccentric radius in inches, and

Wt is the weight of the reciprocating masses.

In the slow speeds, and even those moderately higher, inertia as a strain ranks with friction in importance, and is usually neglected ; but, as the effect increases with the square of the revolutions, and again with the stroke of the valve, it becomes quite a considerable quantity, frequently expressed in tons of pressure in the case of high-speed engines of large powers, whose valve stroke can hardly be too great for proper port opening.

Although the force of inertia of the reciprocating masses is greatest at the extremes of stroke, at the points of reversal of direction of motion, and while they are at rest, it also exists in less degree, but in varying amount, to a point of highest velocity midway of the stroke, where it becomes negative, to again become a maximum at the completion of the stroke.

Ignoring the factor of angularity of eccentric rod, the curve of inertia pressure on the basis of the stroke is seen in Fig. 30 to be a straight line crossing its base line at the center.

The area of the triangles represent the work received and

delivered by the mass in reciprocation, and are equal, while the extreme vertical lines are also equal, and represent the maximum pressures.

The varying angularity of the eccentric rod introduces a com-

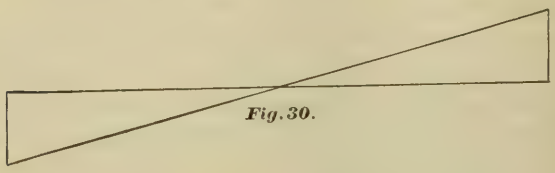


Fig. 30.

paratively slight modifying factor, so that the curve assumes the shape shown in Fig. 31.

The maximum inertia pressure is here seen greater at one extreme of the stroke than at the other; but the areas above

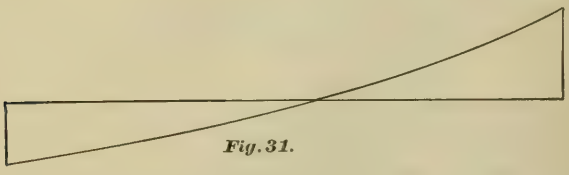


Fig. 31.

and below the line must still be equal, so the curve crosses its base line at some distance from the center.

It will be evident that an expansion curve may readily be fitted to this curve of inertia pressure, and the variation of

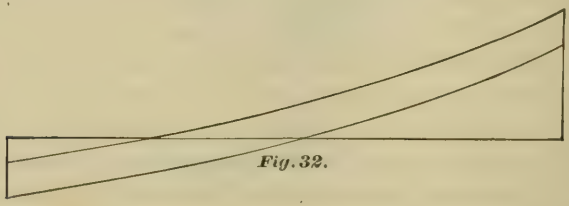


Fig. 32.

pressure represented by it so applied as to practically balance the force of inertia at any part of the stroke.

In a vertical engine the balance, as applied at each half of the stroke, may be unequal, so that the mean effective effort over the whole stroke shall equal and neutralize gravity upon the

reciprocating masses; still, however, maintaining the proper inclination to balance as well the inertia effect, as per Fig. 32.

The vertical distance between the curves represents the neutralizing effect on gravity.

With a properly varying angular movement of compression, it is also perfectly possible to fit a spring tension that shall exactly balance the forces represented by the inertia curve, together with that of gravity.

Under the same speed of revolution of the engine, and with the necessarily varying valve strokes incident to the varying cut-offs, the inclination of the curve of inertia scarcely changes, and may be considered practically uniform, so that the curve corresponding to a longer or shorter stroke may be found by proportionally increasing or decreasing its length on the line of the indicated inclination. Thus Fig. 33.

The crowning excellence of this balancing device is found in

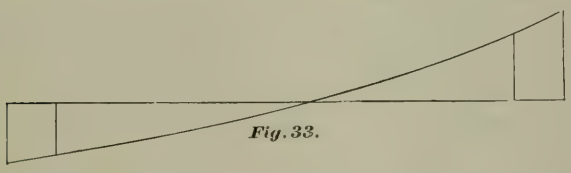


Fig. 33.

its ability to automatically adjust for the new conditions of strain, because the same character of movement that varies the strain likewise and similarly changes the resisting force. The only office of the eccentric becomes then a means of impulse by which a vibration is maintained, since it is no longer called upon for strength of resistance, and may be made comparatively insignificant in size.

From experiment it appears that the varying inertia strain is accountable for the impossibility of perfect isochronism without obstructing mechanisms, and that the application of the inertia balance serves to permit a far higher *degree* of regulation without interfering in the least with *rapidity* of regulation.

At a recent test of the device in an electric light station, on an engine of 500 H.P., running at a speed of 220 revolutions per minute, where the balance found it necessary to resist reciprocating pressures of $2\frac{1}{2}$ tons at each extreme of the stroke, there was not even one revolution difference between the corresponding speeds of no load and full load.

DISCUSSION.

Mr. Frank H. Ball.—This paper is, I think, a valuable contribution to the literature on the subject of shaft governors.

While many of the conclusions may be fairly questioned, I think the author deserves credit for calling attention to one of the manifestations of inertia which has been, perhaps, very generally overlooked.

This he describes as "angular inertia," and although a small force in governors of ordinary construction should not be overlooked.

I do not quite understand why the author describes this "angular inertia" as being "generated by a varying angular velocity about its center of support and rotation." It seems to me that the force is due to the fact that the weight by its connection with the wheel is made to rotate once about its own center of gravity at each revolution about the center of the shaft, and any acceleration or retardation of this rotation about its center of gravity produces an inertia effect on the pin or center of support which either favors or opposes tangential motion of the weight.

The shaft-governor problem seems to me to present three distinct manifestations of inertia:

First, and least of all in importance, the angular inertia about the center of gravity of the atoms of matter composing the weight.

Second, and greater in importance, the angular inertia of the concentrated mass of the weight about the center of the shaft, called by the author "tangential inertia."

Third, and greatest in importance, the centrifugal inertia of the weight, due to its constant forced deflection from the tangent to the circular path.

A familiar example of a combination of several manifestations of inertia may be seen in the case of a rifle ball discharged horizontally.

The spiral movement or rotation about its center of gravity is resisted by friction of the atmosphere, and develops or manifests angular inertia about its center of gravity, although this force is only in a remote way parallel to the same force in the governor problem.

The rifle ball in its onward course is drawn by the force of

gravitation from the straight line into a downward curve, and here inertia resists this curved path much the same as centrifugal inertia in the governor problem resists the circular path.

The resistance of the atmosphere to the motion of the rifle ball in its curved path is met by the inertia of the ball, and is not unlike the angular inertia of the governor weight in its circular path around the shaft.

The time allotted for discussion of this paper is too short to cover the ground as fully as I would like, and I hope later to submit a paper on this subject for the Chicago meeting, which will investigate the various manifestations of inertia in a shaft governor, and will consider the following questions:

First, Whether or not all governors are inertia governors whose movable parts are actuated by a change of speed of the engine without regard to which of the inertia forces are utilized.

Second, Whether or not centrifugal force is one of the manifestations of inertia, and the most important because the greatest, and the only one absolutely indispensable.

Third, Whether or not one of the manifestations of inertia is any more or less prompt in its action than any other, and whether or not they all alike come under the same general law, that matter resists any change of condition as to motion.

Fourth, Whether or not a perfect governor should utilize all the inertia forces of all its moving parts, thus producing a maximum actuating force with a minimum weight of parts.

Fifth, Whether or not any weight in these moving parts, not arranged to lend its inertia to the governing forces, is a hindrance, and any weight which opposes by its inertia any of the governing forces is doubly so.

Answers to the foregoing questions will be sought, and the logic of these answers applied to the conclusions of the paper under discussion.

The practical illustration of the author's theories given in concluding his paper will be examined particularly with reference to the subject of the preceding questions, Nos. 4 and 5.

One thing more in regard to this paper. The opening sentence reads as follows:

"Considering the amount of labor which has been spent upon the theory and method of steam distribution and the mechanical design of steam engines, it is strange that so little work has been done toward perfecting the governor."

Now, there are a lot of designers who have been working away on these governor problems for years, and doing the best they know how, and it is rather discouraging for them to learn all at once that nothing much has been done. Perhaps the author refers only to work published and accessible in print.

This sentence is not unlike that introductory sentence in which we engine builders generally announce, that "we and Watt are about the only people who have ever done much with the steam engine."

No doubt we are all inclined to be carried away with a new idea or demonstration, and to feel that nothing much has been done before on that subject, and we need somebody to call us down, like the king who regularly appointed an officer whose sole duty was to stand at the gate of his palace, and as he went in and out to call out to him, "O king, thou art a man!"

I do not know as we have such an officer in this Society, but perhaps we ought to have one.

*Mr. F. M. Rites.**—There has been no intention in the paper, and no attempt to claim anything like perfection in this example; but, on the contrary, attention has been gratuitously called to faults, which, however, are immaterial in their influence.

There is not even novelty in the arrangement of the essential elements of the governor, for the same old gravity balancing weights are linked together to shift an eccentric across the shaft, so that the only reason for giving the combination space was, as stated, to illustrate such a relative position of mechanical centres, that even a moderate application of inertia forces could result in a vastly improved rapidity of governing.

As the title implies, the only attempt has been to exhibit, generally, the inertia forces which are advisable in governor adjustments, and these are free to be applied to any form as suits the designer.

Professor Klein has called attention to the peculiar character of the equation

$$\frac{r_1^2 r_3}{r_4^2 r^2} = \frac{yz - x^2}{z^2 + x^2},$$

for although the second member increases as x and z approach 0, and is infinity just before this value is assumed, yet the

* Author's closure, under the Rules.

expression is actually 0 when x and z are 0. The reasoning is plainer by a consideration of the first member, for if x and z are 0, r_3 is also of necessity 0, so that both terms must vanish, because there ceases to be an inertia effect.

Professor Jacobus has kindly indicated a double and self-corrective error of mathematical manipulation, so that proper changes have not altered the conclusions.

Professor Klein also shows that the method of obtaining the value of x in equation (7) might be simplified for the constant C in Wt. $= \frac{C.H.P.}{R^3 D^2}$ contains x and b in the relation

$$\frac{x}{b^2 + 2b} = 26;$$

hence, as before, if

$$v = .02,$$
$$x = 1.04.$$

DXI.*

AN INTERESTING BOILER EXPLOSION.

BY FRED. H. DANIELS, WORCESTER, MASS.

(Member of the Society.)

In these days of high-pressure steam, the construction of boilers becomes a study of great interest. Responsible makers are alive to the question and use all possible means to insure the strength and safety of their product, in order to prevent more or less disastrous failures. Accidents will, however, occur, and when they happen, engineers are always ready to study cause and effect, in order to draw some conclusions which in the future may be of great value. A report upon a peculiar rupture which took place in one boiler of the steam plant of the Washburn & Moen Manufacturing Company, Worcester, Mass., may therefore be of interest to many of our Society.

Six years ago they equipped a portion of their plant with a battery of six horizontal tubular boilers, from plans furnished by H. S. Robinson & Co. The boilers were 5 feet in diameter, with tubes 19 feet 8 inches long, and were designed to carry a working pressure of 125 lbs. to the square inch. The advantages of subjecting materials for boilers to a careful test by the consumer, before accepting them, were brought to our attention by Mr. H. S. Robinson, senior member of the firm mentioned, and we decided to have all the materials for our boilers, especially the shell plates, tested in a very exhaustive way at the Watertown Arsenal, before permitting any of the material to be used. One plate out of the entire lot was condemned. These boilers have been in successful operation for nearly six years and are still in use. They are inspected every week. The water is run out, the man-holes removed and the interior as well as the exterior of the boilers carefully examined. As the water in the streams in the vicinity of Worcester is very pure, coming

* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

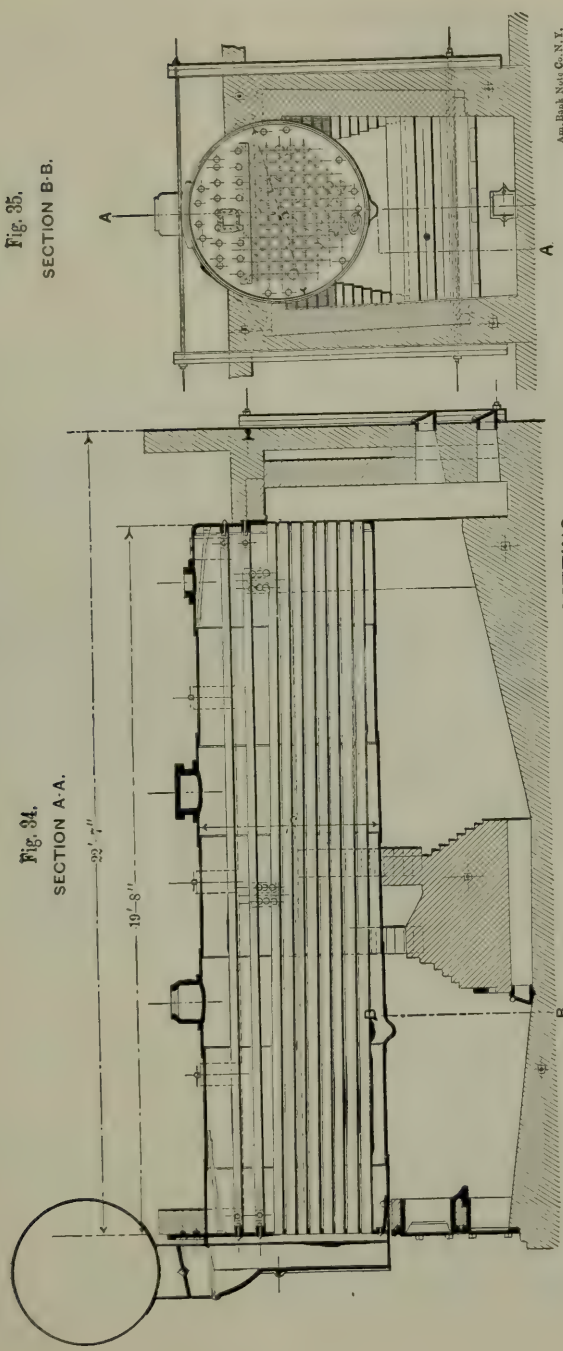
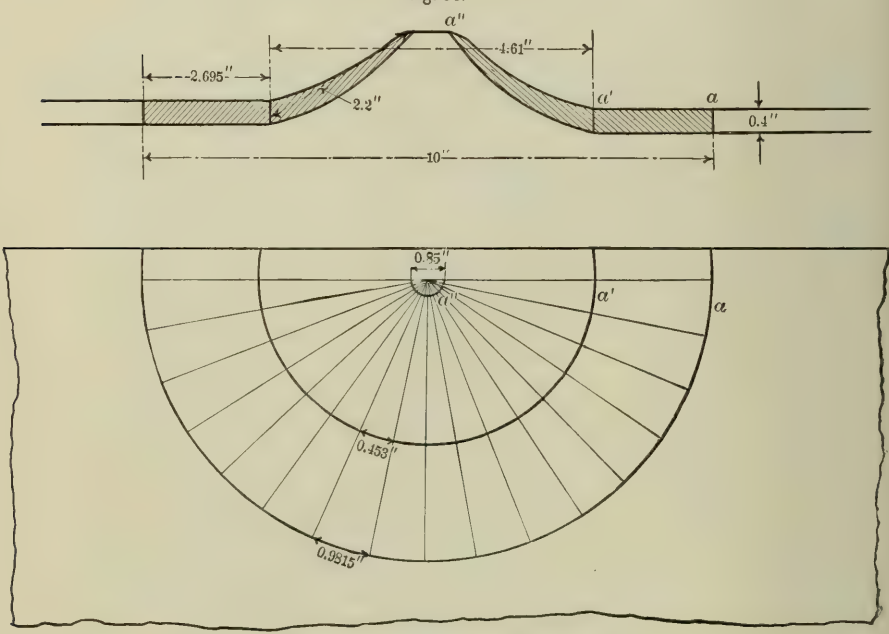


Fig. 35.
SECTION B-B.
A
A
Am. Bank Note Co. N.Y.
Fig. 34.
SECTION A-A.
22'-7"
19'-8"
B
B
BOILER AND SETTING
WASHBURN & MOEN MANUFACTURING CO

as it does from the granite hills, we never find scale in the boilers, but in the spring and fall, during high water, it is not uncommon to find a small deposit of débris, which is carefully washed out.

With all this care, the accident was to us a real surprise. When it happened, the plant was running as usual, but the boilers were somewhat forced, although not to any extreme limit. Without any warning whatever, and with very little noise, the firing doors of the furnace were burst open, coal, ashes and

Fig. 36.



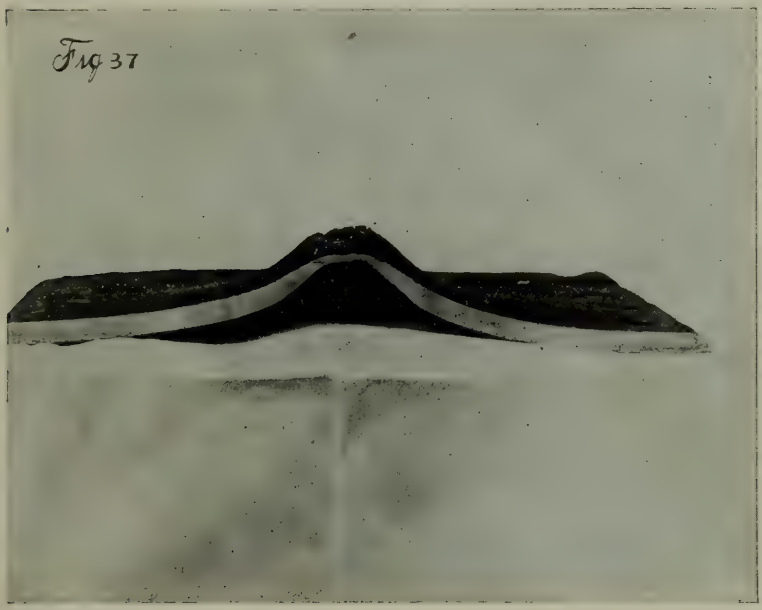
SECTION AT POINT OF RUPTURE

water thrown out, and the boiler house, in an instant, filled with steam.

As soon as an examination could be made it was found that one of the plates in the third row, just over the most intense heat, had bagged and ruptured, leaving an orifice about 1 inch in diameter, thinning the metal around the orifice to a knife edge. The remainder of the shell was not damaged, because the boiler quickly emptied itself of water and steam, which extinguished the fire and cooled the brickwork. The accompany-

ing drawings (Figs. 34 and 35) illustrate the exact location of the rupture, also the arrangement and details of the boiler and setting. A careful inspection failed to discover scale or débris of any kind inside the boiler. The other five boilers of the battery were also examined at the same time, and we found two of them with their lower sheets slightly wavy, but nothing approaching a bag. The ruptured portion was cut out and a patch supplied in its place. The boiler has been in constant use since, without any further sign of failure.

Upon examination of the cut-out piece (exhibited at the



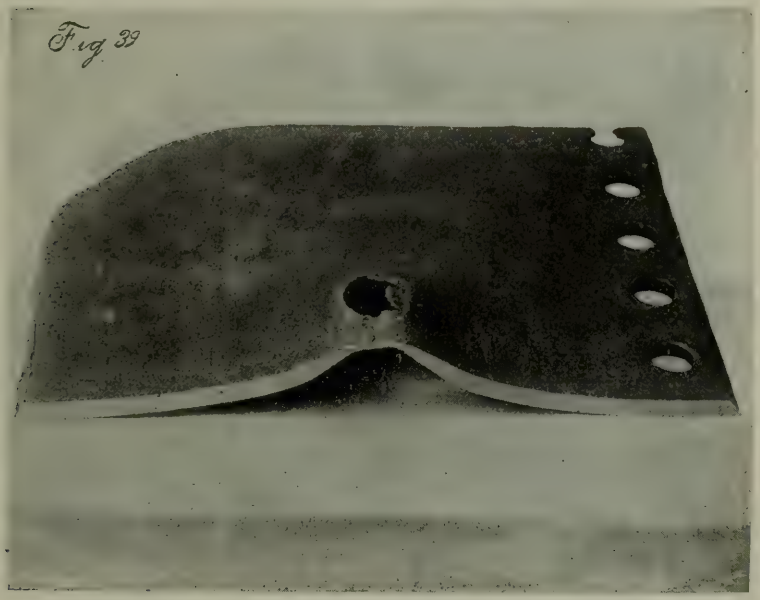
reading) we found a very thin black scale around the rupture, and nearest the orifice it looked as if the plate had been highly heated, so highly, in fact, as to permit the cutting away of the hot metal. We carefully calculated the cubical contents of the plate (see Fig. 36), and found that there were 1.41 cubic inches less material in the half 10-inch circle, after rupture, than there was in the plate before. These figures, together with a careful examination of the plate, seem to indicate that for a few moments before the rupture the plate was subjected to a very high, possibly to a white, heat, and when the metal became sufficiently plastic and was in a proper condition for such a result, it

simply flowed out, as shown in exhibited plate herewith, or in Figs. 37, 38, 39, and 40. It seems reasonable to suppose that this plate had been overheated for a very few minutes only, and that previous to the time of rupture it had been in perfect condition, for the boilers were carefully inspected only four days previous to the accident and everything was found in good order. Two or three times during the past twenty years we have had boilers bag, but never before had one rupture.

All of the shell plates in this battery of boilers were stamped with numbers, and the original report on the tensile strength

tests preserved. By referring to these records we found that the plate which was ruptured had on one end a tensile strength of 68,050 lbs. and on the other end 65,650 lbs. per square inch. It also stood well the "burr test" for annealing and water chilling (see exhibit of "burr tests," how they are made). By way of comparison, two test pieces were planed from the ruptured plate. (Test pieces were exhibited at the reading. See also Figs. 41 and 42.) The test piece which was farthest from the bulge held 60,486 lbs. to the square inch and had a reduction of area of 41%. The test piece close beside the rupture held 61,666 lbs. to the square inch and had a reduction of area of over 32%. It will be observed that the tensile strength is con-

siderably less in the ruptured plate than in the original tests of the plate. This may be accounted for, however, by reason of the test piece having a twist in it, occasioned by the bulge in the plate, and having been put into the testing machine without straightening. "Burr tests" were also made. One of them, heated high and allowed to cool in the air, was hammered together as shown; the other, heated to redness, and plunged in cold water and hammered as shown, without failure (exhibited



"burr test" made from the bulged plate). The analysis of the ruptured plate is as follows:

Phosphorus	.063%
Sulphur	.022%
Silicon	.024%
Manganese	.261%
Carbon	.10%

It has been suggested that this thin scale covered the entire surface over the fracture before the rupture, and was caused by oil which had become burned on to the plate; but as the feed water for this plant was supplied from a closed heater, it is difficult to see how oil could have found its way into the boiler. We have been informed by Mr. Robinson that he was called, a

short time ago, to examine a boiler of the same construction as the one referred to in this paper. It had been overheated directly over the fire box, making the shell plates wavy. After carefully drawing the water from the boiler, nothing could be discovered on the plate excepting a whitish powder. There was neither scale nor mud.

The conclusions the writer arrives at are, that the importance of mechanical, physical, and chemical tests cannot be overrated.

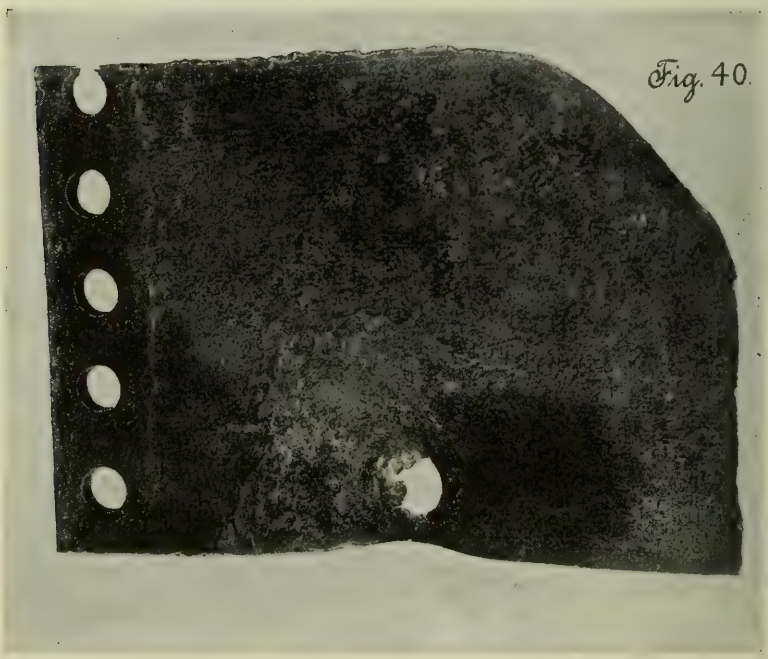
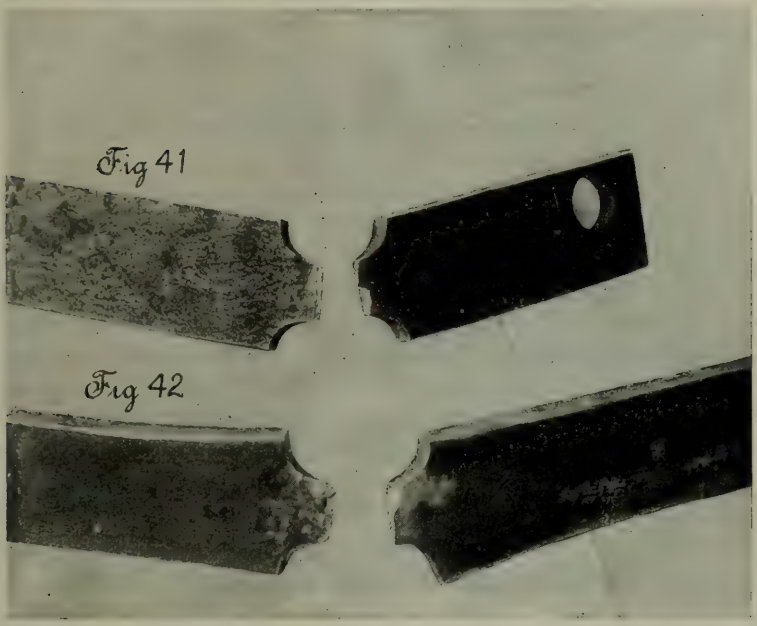


Fig. 40.

While the plate makers invariably subject their plates to tests and stamp them accordingly, at the same time, a confirmation of quality by the consumer is desirable, for we have seen that, in the tests at Watertown, one plate was condemned. If the ruptured plate had been of improper material or had contained sufficient carbon to harden when the water came in contact with the overheated plate, a crack might have developed, resulting in a serious explosion, possibly destroying the entire plant and causing a loss of life.

In closing, we wish to compliment Mr. H. S. Robinson, who constructed these boilers for us, upon the very perfect system

which he has had in use for the past nineteen years, of checking the tests of plates to be used in the work produced by his firm. During this time, all the plates of the boilers produced by them have been re-tested and a complete record preserved of the tensile strength and the "burr test," at the same time recording



the location of each plate in the boiler by properly stamping them. This system is of great value to him and to the consumer, for any defects can then be traced and fully investigated.

DISCUSSION.

Mr. Allan Stirling.—In this valuable paper Mr. Daniels has contributed to the Society a complete record of an interesting accident which, on account of the excellent methods adopted, can scarcely be called an explosion. Horizontal tubular boilers frequently give trouble at this point. Mr. Daniels says that "two" of the "other five boilers of the battery" were found on examination "with their lower sheets slightly wavy." Several plates had "bagged" in the mill before, and the manufacturer of these boilers found another boiler lately that had been over-

heated directly over the fire-box, making the shell plates wavy. Many of the members of this Society have no doubt had these experiences. Bulges and patches are frequently found on horizontal tubular boilers at this point. These are more frequent where the water is bad, and in that case the explanation usually given is that the scale keeps the water off the plate and the plates become overheated. But the case reported by Mr. Daniels cannot be explained in this way. The water came from granite formations. Both the interior and exterior of the boilers were examined every week, and there was neither scale nor oil; and yet with plenty of water in the boiler the bottom plate was overheated and burned so much that it bagged and blew out. The following is a reasonable explanation of this and other similar occurrences. The horizontal tubular boiler has the heat applied to every foot of its surface of plates and tubes below the waterline. The result of this is that in every part of the boiler steam bubbles are rising, so that there is no place for the return circulation. When the boiler is making steam freely, the water is evaporated from the plates and it is impossible for more water to reach the plates promptly; they are overheated and burned and the pressure bulges or ruptures them (see sketch). Leaving out the central vertical row of tubes has been tried as a remedy for this, but even then the water cannot reach the plates at the bottom of the boiler promptly on account of the rising bubbles of steam. It is not necessary to assume that the plates are at any time heated to a white heat. It is probable that they are repeatedly overheated and cooled and gradually oxidized and thus thinned sufficiently for the pressure to have the effect described. I am sure that every member of this Society will agree with Mr. Daniels as to the importance of careful testing of plates. It is apparent, however, that this is not all that is necessary to insure the safe and satisfactory working of boilers. The design of the boiler is fully as important, and it is manifestly for the interest of boiler users to select a design which removes the plates entirely from the action of the flame and insures a thorough circulation of water to every part of the boiler to take the place promptly of the water as it is evaporated. The horizontal tubular boiler, when making steam freely at high pressure, is a constant menace to life and property.

Mr. Jas. McBride.—I do not know that I have very much to say about this particular case, except that I had a case some-

what similar. One single word of four letters explains what was the matter with mine—dirt. I had a boiler very similar to the one described—about the same size, five feet in diameter, not quite so long. It gave out about as shown in the drawing. On Monday forenoon my engineer came to me and said, "There is a bag on No. 8 boiler." I asked when the boiler was cleaned. He said it was cleaned a few days before that—that he knew it was perfectly clean. I had him run the water all out. The boiler looked clean. He said, "That looks all right in there." I got the blacksmith to make a hook and with it I pulled out a handful of scale, finally pulled out half a pail of scale. That accounted for my trouble. I think if Mr. Daniels would take the dirt out of his boiler he would get the cat out of the bag. He was no doubt mistaken as to the true condition of the boiler. While subordinates do not mean to deceive they are sometimes mistaken. We use Ridgewood water, and the largest proportion of the water which I use for the boilers comes from the vacuum pans, and yet here is the result (exhibiting the specimen). You can see the dirt in there yet, and that piece of plate has been kicked about the office three or four years. While this case of Mr. Daniels appears very mysterious, I think the whole thing can be attributed to dirt in the boilers. On Saturday night we shut down about twelve o'clock. The boiler stands until about four o'clock, Monday morning. Everything settles in the bottom of the boiler, and if we start a brisk fire, we are very apt, if the boiler is dirty, to have trouble. My boiler was made in three sheets, leaving a ridge over a quarter of an inch high at the seam so that all the stuff that drifted back made a lodgment at that point, and that is where it gave out. Mr. Stirling says that he thinks it is due to bad circulation; says he cannot understand how water gets down in that horizontal tubular boiler. We know it does get there, even if we cannot just explain it. I doubt if there was ever a case on record where a boiler that was absolutely clean bagged in this way; I do not believe it is possible to put in a fire hot enough to burn that sheet if the boiler is perfectly clean.

Mr. John T. Hawkins.—I would like to say one word about that. I cannot say that I agree with the last gentleman, that we do know absolutely how the water does get down to the lower sheet of the boiler in all cases. I think we do know pretty well in this case. The boiler shown is of a perfectly symmetri-

cal construction and it is presumed to be symmetrical in its action, so far as circulation of the water is concerned; and the escape of the steam from the surface, immediately over the fire, as instanced by Mr. Stirling, must be upward between the tubes, and the return of the water to that surface will be down each side symmetrically. That is the natural action of the convection currents in such a boiler. Now if that symmetrical action does take place, the water passing down each side alike to supply the high evaporation from this surface, is it not probable that at the very hottest place or line over the furnace, the symmetrical action of the water coming down together may form a pocket in which the water does not meet the boiler surface at that place as completely as at others? If you can imagine two streams of water coming down one on each side, it seems to me it would be like the action of water from a fountain where two streams meeting together would make a throwing up at that point. It seems to have occurred over the hottest place in the furnace, and any defect in the metal would suffer most at that place or on a line where such action takes place, while such a defect might not occur at all at a point in the boiler where there was more intimate contact of the water with the metal. I think myself that this occurred in a perfectly clean boiler, not only because the paper says that the boiler was clean, but because it is almost an impossible thing to conceive that mere dirt can anywhere lodge permanently in any part of a boiler where rapid and contending currents are so energetically in progress as we know they must be in a boiler of this kind, and at such a point in it. Accumulation of scale, adhering firmly as it does to the interior surfaces of a boiler, is quite distinct from mere dirt, which is always of the character of loose matter easily conveyed from place to place by the currents of water set up in a boiler. Such matter can only lodge permanently in those parts of boilers where there is practically no circulation; as in the water-legs of internally fired boilers, in mud drums purposely located out of reach of circulation, etc., etc.; but that this was not caused by accumulation of true scale is certified by the fact that none appears on any other part of the interior. It seems to be the result of a concatenation of circumstances in which a weak spot was subjected to the most unfavorable conditions of intimate contact between water and metal.

Mr. Frederick LaForge.—The remarks of one or two of the gentlemen remind me of a little story about the man who got into the stocks, and the lawyer said to him, "What are you doing here?" The man said, "I am in the stocks." "What for?" "Well, the court sentenced me to the stocks for such an offence." "But," said the lawyer, "you cannot be put in the stocks for that." "But I *am* in the stocks," replied the man. The fact is, in regard to the circulation of the water in the return tubular boiler, we have thousands and thousands of such boilers where the water does circulate, and the sheets do not heat up. I have examined return tubular boilers which have been in use thirty years—and have not bulged yet. I have examined them where they bulged after having been used a week. I remember an engineer who used zinc as a scale solvent. He would throw a shovelful of zinc chips into the bottom of the boiler, and shortly he found that the sheet bulged over the fire. I agree with Mr. McBride in the opinion that the solving of this problem is to keep your boilers clean, not only of dirt but also of oil.

Mr. Carleton W. Nason.—I remember an instance which nearly resembled this in appearance, that was clearly due to lamination. The boiler had been running only a few weeks, and it was observed by the engineer that the sheet over the fire was gradually dropping. The protruding point was circular and about 10 or 12 inches in diameter. It was cut out and examined. The plate was not properly welded, there being two thicknesses separated by scale. The inside part of the sheet was very thin, and there was a measurable space between that and the outer portion. There being no contact between the two surfaces, it was evident that the outside of the plate was heated red hot, enough to soften it, and the inside, being thin, gradually stretched and came down. If the defect had not been observed and cut out, the plate would have been ruptured in a way similar to this, perhaps more disastrously. I think, even where plates are not severely tested by the lateral strains, that the difficulty from lamination exists in many of them, unknown, because the conditions of ordinary usage do not severely try them, and that such accidents as the one here shown are by no means uncommon.

Mr. W. B. LeVan.—I was inspector of a boiler company for three years. We had three cases of boiler ruptures which

occurred, of a similar character to this one, and upon investigation we found that the whole difficulty was to be attributed to the party who cleaned the boilers, he having carelessly left a bunch of greasy waste in the boilers. This fact was learned afterwards through the confession of one of the boiler-cleaners.

Mr. H. B. Roelker.—A similar thing occurred on the steamer *Hudson*. The boiler was of steel, half an inch thick, fired under the shell—the same as a land boiler. A bulge occurred under the bottom, which leaked a little and was discovered quickly. The fire was drawn and the place examined. A lamination was found in the plate which ran from the interior surface in a diagonal direction to the exterior surface. It was of about five inches in width in the centre of plate and had small openings where it passed through either surface. If it had not been discovered in time, the openings would have enlarged and a local explosion would have followed as in the boiler under discussion. The boiler was as clean as a marine boiler is supposed to be. The occurrence happened on the first or second voyage of the boiler and was due entirely to lamination inside the plate.

Mr. J. F. Holloway.—It seems to be a guessing match in regard to this bulged plate. There is one thing a little suspicious about the fracture, and that is, the thinness of the plate at the extreme point to which it is projected. It seems to me that a plate of that thickness, simply pushed down by overheating and pressure, would be left very much thicker than the piece which we see here. The extreme thinness of the metal as shown would indicate that it was not caused simply by pressure on the inside of the plate at that point—such a pressure as would be brought on it by a die pushing it into a hole, because such action would not make the plate so very thin; and my guess of the matter would be this, that it was first caused by a blister, or a gas bubble in the ingot. Of course, there are steel-makers here who will say that those things do not occur, and they will get up and say so after I get through. But it looks to me as though there was in that ingot a gas bubble or something of the kind, and that made a lamination. Of course, the plate being steel, lamination could not occur from piling, as we often see it in iron plates.

Mr. Geo. H. Babcock.—We may set it down as an axiom that no sheet of metal of reasonable thickness, such as is used in ordinary boilers of this character, if perfectly clean and not

laminated, with water on one side and fire on the other, can be burned—overheated. If it is overheated, as this sheet evidently was, there was something by reason of which the heat of the fire was not conveyed to the water. Various things might produce this result. Several of them have been noticed here, and probably this case was caused by one of them. Mr. Stirling's remarks are perfectly just in regard to the want of a defined circulation in the ordinary tubular boiler. With such a lack of circulation when there is a very intense fire at one point, the enormous expansion of the water when made into steam is apt to keep the water away from that part and cause some overheating, but generally not enough to produce such an effect as that shown in this case. I do not think that cause alone would be sufficient to produce this effect. Such overheating would be more general; it would not be so defined.

The other cause which has been referred to by Mr. LeVan and others—dirt—is quite probable. Dirt will gather at a definite point; it will not spread over the bottom of a boiler of that character; because the circulation such as there is tends to bring it toward the point where the greatest amount of steam is rising, and therefore it will gather in a mass frequently over the hottest part of the fire and cause a burning out at that point. And that dirt may not be found after the explosion. If you will examine this piece of steel carefully you will notice that a considerable erosion has taken place through the opening. Those of you who are familiar with the appearance of safety valves after they have been allowed to blow a little will notice the peculiar effect of the passage of steam over a piece of metal, in this case. It shows that while the water was being forced out of the boiler under pressure after the explosion it caused a considerable wearing away of the metal, which accounts partially for the thinness at the opening referred to by Mr. Holloway. It is very marked. Any one looking at it will see the marks as plainly as the traces of glaciers on the rocks. There are also other marks on that sheet which indicate that there was a blister at that point. I think it cannot be doubted that there was a want of homogeneity of the metal so that the heat was not conducted through it as readily as it should have been, which assisted, undoubtedly, in the overheating of the exterior portion of the sheet, and may have caused thinning of the metal by the burning away of the surface, as we know occurs fre-

quently in boilers where there is an intense heat. The surfaces of a locomotive boiler next the fire, particularly if the sheet is over five-sixteenths of an inch thick, are frequently found to be burned away to about that thickness. I believe that it is a rule in the Navy, Mr. Chairman, or used to be, not to allow a sheet over five-sixteenths of an inch in contact with the fire, for the reason that it would burn, with an intense fire, even with the water on the other side. I think there can be no question but that there was in this case some dirt in addition, which dirt was carried away at the time of the explosion. If it had been there it would have been entirely washed away through the opening. It is not an uncommon accident, it is not a peculiar accident, and it is well within the knowledge of boiler-makers and engineers as to the causes which produced it.

Mr. J. J. Butcher.—Much has been said about circulation in a boiler, yet the most important element in that circulation has usually been left unnoticed. The circulation which has been described so frequently is the well-known general circulation in which the water rises over the hotter plates and descends over the plates which are comparatively cool, setting up in so doing compensative currents along the surface, due to differences of level and at the bottom, due to differences of pressure. This circulation is not caused so much by differences of heat in the different parts of the water (which is all practically at boiling temperature, where the circulation is good, and consequently varies scarcely appreciably in specific gravity) as by difference in the extent to which it is honey-combed with steam bubbles. These bubbles are both larger and more frequent over the hotter plates, causing the combined mass of water and steam, cubic foot for cubic foot, to be lighter here than elsewhere. The heavier masses of water and steam, at the parts of the boiler where ebullition is less active, consequently fall in level, causing a depression of the surface, and forcing out the substratum in currents along the bottom, so as to raise the height of the surface of the lighter body of water and steam where ebullition is most active, causing a surface slope from the parts where the most steam is being made, toward those parts where the least steam is being made, and, of course, setting up a surface flow in that direction. It is exactly like the general oceanic circulation as so well explained by Dr. Croll and others. It is well to bear the exact sequence of causes which contribute to

this phenomenon in mind, or confusion will arise, as it has done so often hitherto.

But there is another, and, in boilers of large single water space (non-sectional boilers), a yet more important circulation. I refer to the circulation of the water round each individual bubble. If the life of the boiler year by year and week by week may be said to depend upon the general circulation, that life minute by minute may be said with equal truth to depend upon the local circulation round the bubble, for upon this local circulation depends the displacement of the bubbles upward through the water.

In Fig. 197, A is a bubble of steam being displaced upward through the water. The arrows in the water surrounding it show approximately both the directions and the relative intensities of the currents displacing it. These currents take the directions of least resistances, and are confluent beneath the bubble, driving it upward at a velocity greatly exceeding that of the general circulation.

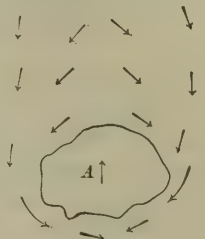


Fig. 197

About twenty years ago I had a most forcible illustration of this action. I was engaged in making a test of a large Lancashire boiler in England, where, to get rid of calculation, and at the same time reduce the conditions to a common basis for comparison where figures were but little understood or believed in, it was thought desirable to remove the cover from the manhole, and let the large column of steam escape through a hole in the roof. For 18 inches or 2 feet this column was quite transparent, not being even streaked with white, and by holding a flaring oil lamp beside it I could see over the whole interior of the boiler. Over the crown sheets the bubbles were 8 or 10 inches in diameter and very frequent. Over the back ends of the flues they were less frequent and no larger than walnuts. Each rose very rapidly, with an oscillatory, probably spiral, motion. When bursting at the surface very little spray was thrown up. The bubbles would, of course, have all been very much smaller under pressure Those at the back and sides often rose to the surface where the general circulation of the water must have been downward. They rose through a descending current.

The bubbles are always formed next to the plate, at a part where the surcharge of heat in the layer of water next to the plate renders the liquid condition unstable. At the point where this heat nucleus is most pronounced a molecule of water bursts into steam, forming a minute bubble next to the plate, and at the walls of this bubble, and at the thin edge of the water next to the plate, more molecules are gaseated until the bubble grows large. The water above the bubble is thus pressed upward and wedged outward by the curved dome, and a local rise in the surface above supervenes which quickly disperses as a wave. The ring of water round the bubble being now subjected to more pressure than the column through it, the water flows down and under the sides of the bubble, dividing it from the plate, from which it at once rises to the surface.

The curvature of the plate has much to do with the easy

Fig.198

Fig.199

Fig.200

Fig.201

separation of bubbles from it. The bottom of a bubble when surrounded by water is concave, and it most easily separates from a plate of opposite curvature, such as the flue of an internally fired boiler (Fig. 198). The crown sheet of a return tubular boiler, having a curve more in correspondence with that of the bottom of the bubble, resists the underflow of the water longer, giving time for a larger growth (Fig. 199). The effect of the first softening and bulging of a plate is to make the bubble cling still longer (Fig. 200).

The circulation of the water round the bubble is the true primary circulation in every steam boiler; the general circulation usually spoken of is only secondary. The former depends upon there being a free waterway round the sides of the bubble. If we place a tube round the bubble (Fig. 201) we cut this waterway, and the bubble is no longer displaced through the water, but moves with it. This will at once show how greatly increased a general circulation is required in a water tube boiler to free the tubes from steam and prevent their filling with it. It was the failure to understand this principle that resulted in the heavy

losses on the boilers of the celebrated *Propontis*, and on the two ships fitted with water tube boilers and sent out of the Tyne at about the same date. From then until now the chief efforts of water tube boiler-makers have been to increase the general circulation to such an extent as to compensate for the loss of the local circulation of the water round the bubble. These efforts have been successful in the best types of water tube boilers, and the great stimulus to the general circulation which has resulted seems likely to bring about unexpected advantages, to understand which we must briefly consider the general laws controlling the precipitation of sediment.

Both the scale and the mud deposits in boilers are primarily caused by the precipitation of sediment. Precipitation in boilers obeys the same laws as it does in rivers, and we must turn to the work of a great American engineer—Captain Eads, of Mississippi fame—for a rational explanation of it.

(*a*) The sediment-bearing power of a stream, cubic inch for cubic inch, decreases with its increase of depth. Thus, other things being equal, a flowing stream in a 3-inch tube can bear a heavier load of sediment than a similar stream, similarly moving, through a 4-inch tube can do. This is because sediment is *continually falling* in every stream, just as it is in still water, but is just as continually tending to be washed up into the stream again by the friction of the latter against its bed. Thus its carrying power depends upon its erosive action against its bed, and upon the comparative efficacy of the eddies thus set up within the body of the stream to retard reprecipitation. The comparative effects of both these factors decrease as the depth of the stream increases.

(*b*) The sediment-bearing power of a stream increases with the square (or perhaps a higher power) of its velocity. This also follows from the fact that the erosion of the bed is the primary factor. Thus if a sediment-bearing stream, flowing over a sedimentary bed (both sediments being of the same quality), will at velocity A just bear its load of sediment and no more, at velocity $.9A$ it will precipitate more sediment, and at velocity $1.1A$ it will pick up sediment from its bed until the increase of load reëstablishes the equilibrium.

(*c*) The sediment-bearing power of a stream decreases with an increase of size of the particles of sediment, because their weight is thus increased as compared with their surface friction, and

they fall through the water more quickly. For the same reason, this power decreases with an increase in the specific gravity of the sediment.

These general laws, first elucidated in regard to great rivers, can all be applied with equal force to the action going on in a water tube boiler.

The relation between the precipitations in the tubes and mud drum of a given boiler with a given sediment depends upon the relation between the current velocities in the tubes and the mud drum. In a case where the velocity in the tubes and headers is sufficient for the load of sediment to be held in suspension, and the tube surfaces kept clean, and the mud drum is still enough and large enough to deposit as much sedimentary matter as is brought in by the feed current in suspension and solution, the amount of sediment in the water within the boiler will remain normal, and the whole will be ultimately deposited in the mud drum.

These principles lead to the hope that, in the future, a boiler will be constructed in which the bugbear of sedimentation, with its annoying accompaniment scaling, will be permanently avoided. To effect this end the precipitation in the mud drum must equal the amount of sedimentary matter brought in by the feed, at a time when the load of sediment carried by the circulating currents in the boiler is below that at which precipitation would occur under the conditions controlling it.

The cause of the well-known danger arising from a skin of oil next the plate, and on the water side of it, seems never to have been understood. Let us look into what will occur in detail, and in the light of the previous discussion of local and general circulation.

The boiling point of the oil would be usually above steam temperature. Let us suppose a special case in which the boiling point of the oil is 500 °and the steam temperature 350°. While the local temperature of the plate beneath the oil keeps below 500° the pellicle of oil will remain liquid. Liquids are poor conductors of heat. The two new surfaces of the oil—the under and the upper—are still more serious obstacles to the transmission of heat. These combined thermal impediments will certainly cause a local rise in the temperature of the plate. But as the plate rises in temperature under the oil the "head of heat" between the inner surface of the plate and the under

surface of the water (from which it is only divided by a thin oil film) increases, and, where there is so great a latitude as 150° between the boiling points, this increased head will, under most circumstances, overcome the resistance to the transmission of heat while the oil remains liquid. In such case no danger will arise, as the plate may rise to 500° or more without material change of strength. This is probably why ruptures do not *always* occur in oily plates, and when they do occur do not usually do so immediately.

But the thermal conditions are unstable. It is obvious that any change in the intensity of the fire will cause a corresponding change in the local temperature of the plate beneath the oil. Such conditions if continued might, by continual slight heatings and coolings, cause bulging and ultimate rupture. But, before any harm occurs from this cause, it is more likely that some slight forcing of the fires may raise the temperature of the plate for a few minutes to above the boiling point of the oil; and here instant danger ensues, for a film of oil gas is at once formed between the skin of oil and the plate, forming a new obstacle to the passage of heat so powerful that it cannot be overleaped. If the skin of oil would all evaporate the danger would be avoided, but this will not usually be the case, because the temperature of the skin of oil next the water is kept down by the latter to 350°, above which it cannot rise appreciably. The oil bubble thus formed will be very thin and flat, for the moment the liquid oil lifts from the plate, no matter how slightly, evaporation ceases, and the remaining oil is cooled to the water temperature, however high the temperature of the plate may be. The circumstances would be somewhat similar to those occurring in the well-known spheroidal state assumed by liquids on very hot plates.

If the film of liquid oil should break, the gas beneath it would escape and the danger be diminished. But an oil bubble has greater cohesion than a water bubble, and the extreme flatness of the film, and the fact that it would closely follow the curvature of the plate, would tend to prevent its rupture by the currents of circulating water. If these various conditions insure its stability for only two or three minutes, the plate, already hot, will rise to the softening point and a blow-out ensue.

In conclusion, it may be well to remark that the danger seems

greatest when the boiling point of the oil is only a little above that of the water.

Prof. J. E. Denton.—It is now a well-established fact that furnaces can be made to bulge from overheating, due to the presence of a very thin film of scale, formed on the fire surfaces by the sinking of oily matter laden with the salts of lime eliminated from water by heat. The experiments of Professor Lewes have shown that such scale may be so thin as to escape the attention of a boiler cleaner.

In the absence of an analysis of the thin scale, admitted in the paper to have been found on the bulged surface, it is quite possible that the cause of the explosion was the non-conducting property of such scale.

Mr. Holloway.—I would like to ask Professor Denton what becomes of a boiler that has a quarter of an inch scale all over.

Mr. John Platt.—I think we may gather from what all the speakers have been saying that probably this explosion was due to scale in the boiler. Mr. Holloway has just asked what should we do if we had boilers with scale half an inch thick. I have seen much worse cases than this. I think we can safely say that the fact that this externally fired type of boiler has lasted so long in this country, is due to your having such very pure water. In English factories, we have to put up with water that will deposit a scale of half an inch inside of a few weeks. I have frequently been in boilers which have been running for some time with scale an inch and a half thick. Of course, this is in out-of-the-way places, where they do not pay proper attention to the boilers. Still, these boilers do not burst. Coming back to this boiler, we have one in which the hottest part of the fire is at the bottom, and we know from experience that this is the place in which the greatest amount of deposit will collect; we thus have the deposit in the worst place.

Is not the frequency of "bagging" in boilers of this type attributable to this fact? One thing, I think, has been lost sight of, and that is that these boilers are carrying 125 pounds pressure and are made of steel. The boilers may be very good for 60 or 70 pounds, but now that we have got to 125 pounds pressure and a 5-foot boiler, the circumstances are quite different. Take the Lancashire form of boiler, which is fired in the flues. You get the hottest part of the fire at the top of the

flue, but there seems to be no tendency for the scale to accumulate at this point. In going through a great number of these boilers, I found very little scale on the hottest part of the boiler, and most of the scale in the bottom. This is the place the scale will collect in the return tube boiler, which leads me to think that this form of boiler is one which is not good for these high pressures and using steel plates. We find from the report of the Manchester Mechanics' Association, and their investigations lately, that these failures of boilers have been very frequent in the last few years; so much so, that they have gone into the question very thoroughly and have come to some very excellent conclusions. This point, and the fact that steel is used in this form of boiler with high pressures, leads us back to what is said in the paper, namely, "that very careful tests are made," and this undoubtedly should be. With one or two English boiler makers, every plate that goes into the boiler works is tested very carefully. One maker has carried this thing out to such an extent that a firm like Sir William G. Armstrong, Mitchell & Co. (Limited), will send an order for twenty boilers, and will trust to that firm to inspect them and not send an inspector to see a single boiler; and I have used boilers made there myself, that have been treated in this way. Does not this lead us to the fact that it is not desirable to put in boilers made by any little firm, and that it is much better to go to a firm that makes good, reliable boilers? Somehow engineers in this country seem to get the idea—if we want a boiler we will make it ourselves; and they set it out—and it is a set-out sometimes.

Mr. O. C. Woolson.—If I had not examined this plate I could readily believe that it was an accumulation of dirt which had caused the rupture, but the appearance of the plate, to me, shows it to be a laminated plate. At the same time, I do believe that an accumulation of dirt in the boiler will produce just this result, for I think it is impossible to clean a boiler so clean that after it has been fired up the little particles that have been left on the tubes, or around on the shell, will not be gathered by the circulation and deposited at just such a point as this; and when that occurs, and there is a blower used in the furnaces, I think it is quite liable to produce this result. If the author of that paper were here, I wanted to ask him if the boiler was run with a blast of any kind. I have seen furnaces

run with blowers which produced a blow-pipe blast, so intense, against certain spots on the under side of the shell that if the water was not kept directly on the shell continuously it must necessarily burn ; and if there is any one here who can answer this question, whether they ran that boiler with a blast, I would like to know.

Mr. R. W. Hunt.—I do not rise to answer Mr. Holloway's question in regard to steel. With my record before the highest court which has ever convened in this country,* and with which you are so familiar, I would not dare to venture an opinion, and I have hesitated saying anything in the discussion of this paper, as it might approach shop. But, as I have been given confidence by some gentlemen who have preceded me, I venture to express my gratitude that the opinions and the criticisms have been so universally in favor of inspection, and I only trust that the spirit will be made manifest in deeds as well as in expressions. But, seriously, I have occasion to value the importance of inspection, whether grists should come to my mill or not. I will venture to mention an incident which happened within a few weeks. An order was given by a prominent railway company, for a boiler, to a well-known firm of commission merchants, who placed it with a reputable firm of boiler-makers. The specification was very distinct as to the physical and chemical qualities of the steel that should enter into the boiler. The boiler-makers placed the order with the agent of the steel-makers, but neglected to say that the plates should be inspected before being shipped. The result was that the steel was shipped to the boiler-makers without inspection. The boiler was made and sent to the railroad company. They, like good clients, refused to receive it until the makers could satisfy the people who had been authorized to make the inspection that the steel was as specified. Well, with a commercial view of the case, the commission merchants sent to the inspectors some pieces of steel which, they said, represented the steel which that firm of steel-makers were in the habit of making for the class of work, and they should think it would be all the evidence they required. This evidence was not quite satisfactory. But the steel-makers, who had acted in perfect good faith in this matter, submitted tests, both chemical and

* The mock trial of John Fitz, of Bethlehem, Pa., at the complimentary dinner tendered to him by his friends in celebration of his seventieth birthday.

physical, from the same heats from which the plates had been rolled. They were outside of both the physical and chemical requirements. The railroad company stood by their first action and made them take back their boiler, and they are now seeking to have one built from proper material. I can mention another instance, that of a boiler which failed in the works of McIntosh, Hemphill & Co. It gave way at a seam. No lives, fortunately, were lost, nor was great damage done to property. But the evidence of the boiler itself left no mystery as to the explosion. The plate had been imperfect. It was badly laminated. It came from the top of the ingot, and the line of rivet-holes had fallen in this weak place. At the very place where the greatest strength was required, it had the least. Now, most likely the heads of the boiler-making establishment were not to blame for that plate going into the boiler. Probably their men did not report when they discovered it, as they must have done when punching or drilling the holes; and it went into the boiler with disastrous results. Had the steel received proper inspection from somebody, that plate would have been rejected at the mill.

Mr. Oberlin Smith.—As I am neither a boiler-maker, a steel-maker, nor an inspector, I venture to say a word. I think it goes without saying that we should have first-class boiler-inspection, physical and chemical, and also that we should take the greatest pains to keep the boilers clean. The third evil that we are all guessing at, as to whether the water stays down on the plate at that hottest point, is one that ought to be investigated. I would like to ask if any one present has made experiments of that kind. It has occurred to me that a small pipe, running down between the tubes or at the side of the shell and nearly touching the bottom at that point, with a cock mounted upon its outside terminus, so that the substance in the pipe, whether steam or pure water, or a mixture of both, might be examined at different times, under different conditions of heat and fire, would possibly be a practical method. It is to be hoped that some means will be devised for actually finding out whether there is water there, or steam, or nothing.

Mr. Chas. H. Manning.—As I have been unable to follow the discussion, I may perhaps borrow some one else's theory without knowing it. It is very evident that the thing was caused by the heat in that spot; there is no doubt about that, that

the water was excluded in some way from the other side of the sheet over that one small place. Now I know that at a former time at these works they were troubled with sewage in the water they fed from, and had to change their source of supply. Whether any of the old pipe was left in or not I do not know. My idea is that, either from that cause or some other, a small globule, consisting of two or three drops of oil, accumulated. These, in passing around with the circulation of the boiler, gathered naturally all the other mud and sticky stuff, making a nucleus for such things to accumulate around. In the circulation around, this got caught in that one spot. The steam formed under it. If it had been a hard scale it never would have done it, because it would have broken and allowed the water to come in. But it lay right down on the sheet, and then there was formed a small pocket of steam underneath, held by the pressure of water and pressure of steam above. That excluded the water from that sheet, and it melted right through there. Of course, when the steel gave way underneath, the water followed through and the whole action was done away with. I think that is about the only plausible theory that can account for the thing. I think, to go back of this, that the type of boiler is faulty of itself, that an externally fired boiler is wrong to begin with, and the position of the boiler is wrong also. The boiler should be turned up on end. (Laughter.)

Mr. Babcock.—May I beg the privilege of answering the question which was raised here a short time ago as to what we would do with boilers with half-inch scale—why do they not burn out? They do burn out if that scale is directly over a hot fire. But usually such a thickness of scale does not appear in that place. Then there is a great difference in scale. There are some scales an inch thick which would not keep the water away from the sheet sufficiently to burn it out, where another scale an eighth of an inch thick would do it, under the same circumstances. A difference in the porosity of the scale has a very different effect in causing the iron to burn out. Mr. Smith asks if anybody has made any experiments to determine whether the circulation is as stated or not. I remember a boiler somewhat similar to the one described but full of tubes and turned up on end, as Mr. Manning says, with the fire built inside. It was a very tall boiler. I have known the water level in that boiler to vary 4 to 6 feet in a few minutes. There is

every reason to believe that when that water was highest there was a good deal of steam below it. A number of other instances could be given, but that illustrates the well-known fact that in some types of boiler the water does not get down sufficiently fast to keep the surface covered. and therefore frequently, when the boiler has been fired very hard, burning takes place, even without much dirt or scale. I think, however, there is not any question but what in the case under discussion there was a localization of dirt.

Mr. Oberlin Smith.—It is very well known that in some boilers the water does not stay down, but what I would like to ask is, whether in this particular type of boiler the water always stays down, and I think it ought to be found out experimentally.

Mr. Chas. A. Hague.—Mr. Manning has touched upon the most important item in the case, and that is the presence of oil within the boiler. I have seen the effects of oil in boilers illustrated in cases wherein surface condensers had been substituted in place of jet condensers ; and such change of condensers being the one alteration of conditions, it is fair to assume that the cylinder oil from the engine, discharged with the exhaust steam, was carried to the boilers in the feed-water thus furnished by the condensed steam ; the feed-water, as sometimes happens, not being strained. I remember a case distinctly, wherein two boilers of the class set forth in the paper just read, bagged very badly in the sheets over the fires, which, however, was discovered in time to prevent serious accident. The difference in the condensers was all the difference that was known, and I think that the accumulation of oil, especially as the oil will accumulate other matter with it, is chargeable with the damage

I presume that this action occurs in a great many cases, and just as soon as a pocket is formed between the sheet and a small portion of what might be termed elastic scale, superheated steam could be produced in a small quantity, and the sheet thus protected from the contact with water would very soon burn out at that particular spot, very possibly producing just such an effect as is shown by the piece of plate now exhibited.

The oil brought into conjunction with dirt in the boiler is no doubt responsible for the blow-out, it being remembered that very nearly an equilibrium would exist between the inside and the outside of the "scale pocket," the superheated steam expanding just enough to keep the scale bubble away from the

plate. These bubbles of semi-elastic material may form oftener than we know, but split open by their internal pressure before the plate is heated up to a damaging point; thus letting the water again down upon the metal, and preserving the plate from overheat.

Mr. John C. Kafer.—Without desiring to extend this discussion, I want to make some observation respecting Professor Denton's remarks on the formation of scale and Professor Lewes's experiments published in the *Proceedings* of the Institution of Naval Architecture of Great Britain. I have had some experience in relation to this. There is a film—it can hardly be called oil—that forms on the top of a crown sheet of the modern boiler of both the corrugated and plain surfaces. There is no question but what this film is caused by oil and dirt—it can hardly be called scale. In a boiler where there was, without doubt, six or eight feet of water above the crown sheet, the crown sheets have gone down as much as 18 inches; and without question this was caused by the film keeping the water away from the surface of the iron. It is strange that this should occur in a boiler having two furnaces fed with exactly the same water, having about the same temperature of the furnace; that one furnace will go down and the other will not. Many of these furnaces have been running for years without any falling at all, while others run but a short time before the furnace comes down. I believe the only way to have them perfectly clean is to scrub them well with lye every week, or after each run when oil is used in the cylinder. On some of the transatlantic steamers they are endeavoring to run without any oil whatever in the cylinder, simply for the purpose of preventing this deposit on the crown sheets. If scale one-quarter of an inch or one-third of an inch, even, in thickness forms over the crown sheet of a boiler and you burn coal at the rate of 5 or 10 pounds per square foot of grate per hour, it will make very little difference in this furnace, as the heat is not great and there is not much to transmit; but when you burn from 30 to 50 pounds of coal per square foot of grate, your trouble begins. The water is boiled so rapidly that it drives the water from the iron unless this iron is perfectly clean.

The cause of the accident to the boiler under discussion, to my mind, is a collection of dirt and, in addition, probably blistered iron.

Mr. J. G. Winship.—A number of years ago a feed-water heater was introduced in this market and had quite a run for a time, but people who were using it found after a while that the crown sheets of their boilers bagged, similar to this case. Investigation showed that grease from the engine going into the boilers, forming into balls and becoming deposited on the crown sheets produced the result. Consequently, these heaters soon went out of the market. They were of the kind known as "jet heaters," the steam coming in contact with the feed water. That was twenty years ago.

Mr. Robert Cartwright.—I do not take any stock in the oil question. Oil is of lighter specific gravity than water. I do not think that oil will settle down there at all. By an examination of the boiler I think it is a physical defect. With all due regard to inspection, it is impossible to inspect that part of it. We know that the magnetic oxide or black oxide may get in—there may have been that feature in this case. I have seen it in plates that have been inspected and accepted by the authorities, and I have seen an inspected plate five-eighths of an inch thick broken by an empty cart running across it. I think the defect was a physical defect. The plate to me shows what appears to be a lamination there that may be of the black oxide, and when that occurs it is like an aneurism in anatomy; it never has a chance to recuperate, but keeps growing in the line of least resistance, and this would make that feature in the plate. This fact is well known in forging. I have seen a paddle-wheel shaft that had been built up or fagoted on a 4-inch square bar; when the shaft broke, the centre 4-inch bar was taken hold of with a pair of tongs, and pulled out of the centre of the shaft, owing to the fact that the magnetic or black oxide did not allow a union, as the centre bar had not been brought up to a welding heat.

The fact is well known in forging that if the hammer is not heavy enough to make thorough work all through you make a poor thing of it. There is a crank shaft in service now that in cutting out the crank pin space, a hole in the centre of the shaft developed itself. I ran a wire in it 26 inches. The inspector was, of course, called upon for an inspection and condemnation. But when he condemned it, I said, "That shaft is stronger with that hole in it than it would be without it," and the shaft was accepted. It is now in one of our government vessels. What I describe was caused by the hammer being too light to condense

the material and the black oxide prohibiting a union in the centre of the shaft. I think that the blister on the sheet exhibited is entirely due to a physical defect in the steel *per se*, where no inspection in this world could ever find it, unless a hole was drilled at the point to admit of examination.

Professor Denton.—I want to mention that oil, as shown by Professor Lewes's experiments, is able to sink by joining itself with the carbonated sulphate of lime, and when that scale is analyzed at the bottom of the boiler 25 per cent. of it is oil.

DXII.*

THE STRAINS IN LATHE BEDS.

BY G. W. BISSELL, AMES, IOWA.
(Junior Member of the Society.)

THE object of this paper is to present the results of some experiments made to determine the strains which actually exist or may exist in the beds of such lathes as may be found in any machine shop. The experiments were suggested by similar ones conducted in 1889 at Sibley College, Cornell University, by Mr. Albert Kingsbury, then a student of that institution. A description of his experiments and the results and conclusions derived are here given in his own words, as contained in the Sibley Journal of Engineering.†

"Experiments were made to determine, 1st, the amount of torsional strain in a given lathe bed under given conditions of stress; 2d, the probable effects of such distortion, not only upon the work produced by the lathe, but upon the lathe itself.

"The common design of lathe bed consists of two parallel I-beams connected at intervals by cross-girts, the whole being cast in one piece. Upon the upper flanges of these beams are the bearing surfaces upon which the tool carriage moves. Assuming the original perfection of these surfaces and neglecting the consideration of wear, the chief causes of their distortion are, 1st, change in the mode of supporting the bed from that which existed at the time that the surfaces were fitted; 2d, the stresses set up in the operation of the lathe. Each of these causes may produce complicated strains in the bed; but those of greatest importance are the transverse strains and the torsional strains. The transverse strains were shown by earlier experiments to be very slight as compared with the torsional strains; and only the latter are here considered.

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* Presented at the New York meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*

† "The Crank," February, 1889.

"Experiments were first made to determine the amount of torsion due to changes in the mode of support of the bed. Six lathes, ranging in size from 14 to 26 inches swing, were tested. Each of these was supported in the ordinary way; that is, by one leg casting under each end of the bed, giving four points of floor support. Evidently the weight of a lathe, supported in this manner, will cause changes in the shape of the bed with every change in the distribution of support, such as is occasioned by irregular settling of the foundations, or warping of the floor. The device used for measuring the torsional strains in these lathe beds was rudely constructed, except the micrometer, but would furnish measurements accurate to 0.0001 inch. It was made as follows: into each of three corners of a piece of pattern pine 2 × 12 × 36 inches, was driven a nail so as to project about $\frac{3}{4}$ inch through the board. In the fourth corner was placed a micrometer screw, with the ordinary electric connections, with a signal bell. The four metallic points were thus at the corners of a rectangle 10 × 35 inches. This device being placed upon the bed of a lathe, the metallic points resting on the flat surfaces between the ways, three fixed points served to determine a plane, while the fourth, the micrometer, measured differences of variation from that plane at that point.

"For the first measurements the tail-block end of the lathe was lifted from the floor and a wedge was placed under one foot, thus throwing all the weight of that end of the lathe upon that foot; and the measuring device being in position, a reading was taken with the micrometer. Then the weight was shifted to the other foot at that end, and a reading again taken. The differences of the readings thus obtained from each of the six lathes averaged 0.0314 inch, none of the results varying greatly from this mean.

"Next, assuming that the mean of the readings in each case in the first experiment represented that which would be obtained in the undistorted position of the bed, readings were taken when the lathe stood upon the floor, just as it had been set up. In this way was found the actual distortion of each bed, in the length of 35 inches and the width of 10 inches; and this distortion was 0.001 inch, as a minimum, and 0.02 inch as a maximum, in the several results obtained from the six lathes.

"From these two sets of measurements it is seen that the twisting of a bed by its own weight may be, and often is, con-

siderable. In one or two of the above cases the actual distortion was as great as could be produced by the weight of the lathe alone; how much greater than this it might be in a lathe with legs bolted to a floor which is continually settling, warping or bending under heavy and shifting loads, may be easily imagined.

"To determine the effect of the working stresses in the lathe, a single test was made in a lathe of 16 inches swing. A piece of steel $2\frac{1}{2}$ inches in diameter and 36 inches long was placed between the centers, and besides the usual driving dog, a dog was placed at the other end of the piece, the tail resting on the carriage; then, by pulling the belt until slipping occurred (back-gear in and the belt on the longest step of the pulley), the greatest possible torsion was set up in the piece and an equal and opposite stress in the bed of the lathe. The measuring device being placed on the bed between the head-stock and the carriage, the difference of the readings taken in the strained and the unstrained conditions was 0.005 inch, when the tail stock end was supported on a block at the middle of the leg casting, and 0.002 inch when both feet were on the floor in the ordinary position.

"From this it appears that the four points of support, while likely to produce strains in the bed by the uneven distribution of the support, may yet oppose the distortion produced by the working stresses. It is safe to say, however, that in small lathes, at least, the quantity and distribution of the metal in the bed should be such as to sufficiently resist all working stresses, and that the floor supports should by evident means be prevented from straining the bed.

"The errors produced in the work done by the lathe will depend not only upon the distortion of the bed, but also upon the kind of operation performed upon the work, and the manner of holding it in the lathe. Work requiring accuracy is finished with light cuts, necessarily; hence, only the distortion due to external forces remains to affect that accuracy. But both this externally produced torsion and the torsion due to heavy cuts act to destroy the fit of the sliding surfaces of the carriage, hence to produce increased wear and increased inaccuracy.

"Assuming that when the bed is under torsional stress the tool moves in a much elongated helix about the neutral axis of the bed, it may be shown that a piece of work can be turned on

the centers without any appreciable variation of diameter due to such motion of the tool.

"The probable variation in diameter of chucked work, due to the twisting of the bed under its own weight, was determined experimentally. Into the tool post of a new 16-inch lathe a flat bar of iron was fastened, upon the side of which a small steel plate was held loosely by screws. The carriage was then run up until the live center, turned accurately true, entered a small center drilled in the loose plate; then the plate was clamped tightly to the bar, thus insuring the concentricity of the hole in the plate with the live center. The carriage was then run back 36 inches, and between these two centers was placed a piece having an arm at the end next the face plate; at the outer end of this arm was the micrometer screw previously used, its contact with the face plate being determined with the electric signal bell. The live spindle and the measuring device rotated together; readings taken front and back at the height of the center gave a difference proportional to the amount of deviation of the center on the carriage from the axis of rotation, at the distance of 36 inches from the live center. On shifting the floor supports of the lathe, as in the first experiment, the micrometer showed a difference of readings of 0.015 inch on a circle 13½ inches in diameter. In case this lathe bed were, in actual use, distorted as much as possible by its own weight, there would be a variation in diameter of more than 0.001 inch per inch of length of chucked work, assuming the rate of error to be constant.

"At the end of the last experiment it was found easy to align the live spindle with the ways until the differences of readings vanished, by merely wedging under one foot or the other, as necessary.

"All the lathes experimented upon had beds of the common design, the complicated structure of which renders mathematical comparisons unreliable. The general instability of the design was shown in an interesting way several times during the tests, by the indications of the instruments of changes in the shape of the bed consequent upon changes in the shape of the floor, as the experimenter walked from one side of the lathe to the other."

The experiments of the writer were made with apparatus and methods precisely similar to those of Professor Kingsbury. The lathes used were one 16-inch Reed, one 16-inch Washburn,

and one 20-inch Fitchburg. The forms of the beds are exhibited in the drawings, Figs. 43, 44, and 45. The 16-inch lathes had

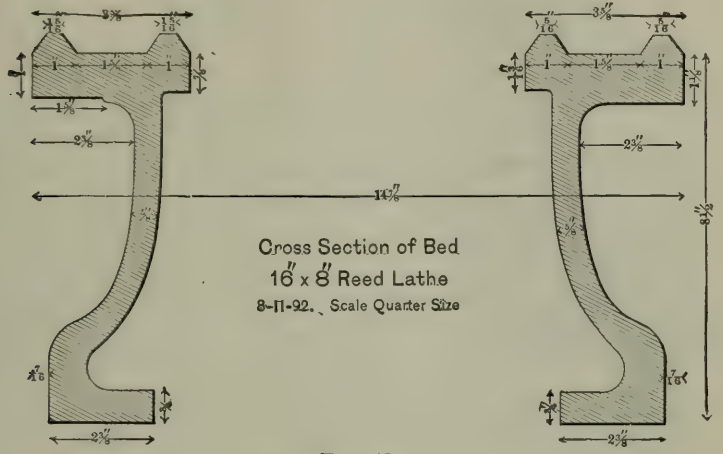


FIG. 43.

beds 8 feet long, and the 20-inch lathe had a bed 12 feet long. All were supported by the familiar leg castings, one under each

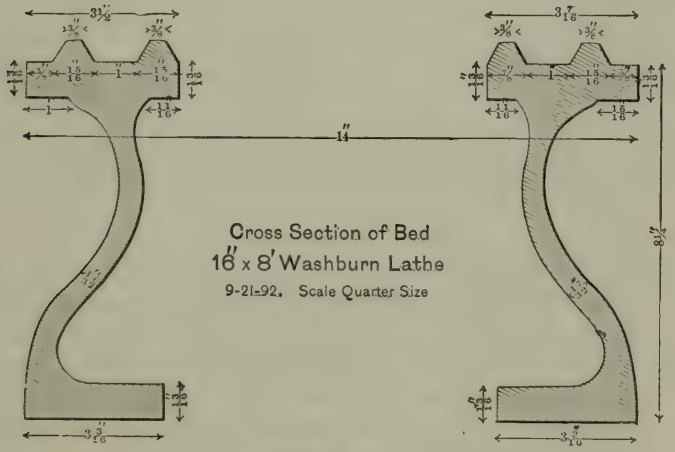


FIG. 44.

end. They are part of the equipment of the machine shop of the Department of Mechanical Engineering of the Iowa Agricultural College.

The observations and the derived data of the tests made by the writer upon these lathes are given herewith :

Size of reference plane, 10 x 36, rectangular.

No. of Observation.	Conditions.	Readings. Reed, 16″	Washburn, 16″	Fitchburg, 20″
	STRAINS PRODUCED BY EXTERNAL CAUSES.			
1	Wedge under front leg, tail-stock end	0.0769	0.0818	0.0760
2	Wedge under back leg, tail-stock end	.1370	.1280	.0099
3	Difference between (1) and (2)	.0601	.0462	.6610
4	Mean of (1) and (2)	.1069	.1049	.0429
5	Normal position of lathe on floor	.1091	.1034	.0256
6	Probable actual distortion in normal position, dif. bet. (4) and (5)	.0022	.0015	.0173
7	Minimum value of (6)		.0015	
8	Maximum value of (6)			.0173
9	Jack screw under middle of leg casting	.1056	.1061	.0456
10	Difference between (4) and (9)	.0013	.0012	.0027
	STRAINS PRODUCED BY TORSION OF PIECE BETWEEN CENTERS.			
11	Normal condition, both feet of leg casting on floor	0.1895	0.1037	0.0244
12	Full belt power, both feet on the floor	.1968	.1074	.0029
13	Jack screw under middle of leg casting, no strain from belt	.1916	.1073	.0598
14	Jack screw support, full belt power	.1946	.1150	.0710
	ERRORS OF CHUCKED WORK.			
15	Front reading, wedge under back leg	.2836	.3169	.1454
16	Back reading, wedge under back leg	.2928	.3146	.2038
17	Difference between (15) and (16)	.0092	.0020	.0584
18	Front reading, wedge under front leg	.2942	.3236	.2005
19	Back reading, wedge under front leg	.2782	.3056	.1935
20	Difference between (18) and (19)	.0160	.0180	.0070
21	Average difference of front and back reading	.0126	.0100	.0327
22	Spindle aligned, difference reduced to	.0004	.0005	.0002
23	Spindle aligned, reading with micrometer and apparatus used in (1) to (14)	.1161	.1269	.0636
24	Difference between (9) and (23)	.0105	.0208	.0180
25	Maximum variation in diameter of chucked work per inch of length	.0021	.0024	.0077

REMARKS.—The observations (24) indicate, 1st, the degree of accuracy attained in the original alignment of the lathe ; or, 2d, the amount of wear to which the parts interested have been subjected; or, 3d, and more probably, combined effect of wear and faulty alignment.

In addition to the above the writer presents the results of experiments made to determine the pressure upon the cutting tool of the lathe, believing that the same will be of interest in connection with what has preceded. The experiments were planned by him as a thesis for Mr. L. B. Spinney, recently graduated from the Iowa Agricultural College. Mr. Spinney built the special apparatus used, designing many of its details, and performed all of the experiments under the supervision of and with occasional assistance from the writer, who has given the work careful attention. Mr. Spinney's conscientious work on this task is responsible for its final success.

It was decided to measure the tool pressure with a modified

form of the Morin dynamometer, the same to be calibrated by means of a friction brake. The lathe used was a 16-inch Reed. A preliminary test was made to determine the maximum effort of the belt in inch pounds of turning moment upon the spindle. To do this a bar of steel, $1\frac{1}{2} \times \frac{1}{2}$, about 5 feet long, was placed in a four-jaw chuck in its place upon the spindle, so that it extended horizontally transversely to the axis of the spindle. Under a point of this bar, 2 feet from the center of the spindle, was fixed a knife-edge support resting upon a platform scales. With the back gear in and the belt upon the longest step of the

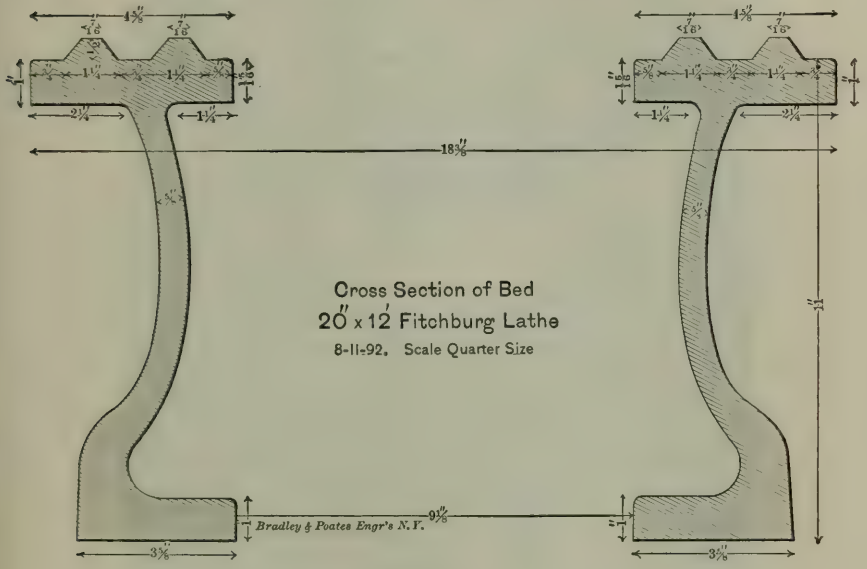


FIG. 45.

cone pulley, the belt was driven to the point of slipping and the load on the scales noted. Tare was determined and allowed for. Several observations with varying leverages were taken, and the average of these showed a moment of 2712 inch pounds. This quantity was used in calculating the dimensions of the leaf springs of the dynamometer. The width of the belt was $2\frac{1}{2}$ inches. Drawings of the dynamometer are shown in Fig. 46, which contains side and end elevations. The foundation of the dynamometer was the face plate of the lathe (Fig. 47). The recording mechanism is automatic, and is based upon a common clock wheel train, at one end of which is the disk carrying the diagram

cards, and at the other is the lead weight which gives to the train its motion relative to the pencil point and to the face plate. Owing to its weight and to the slow rotative speed of the spindle, this proved a very efficient device for the purpose. The

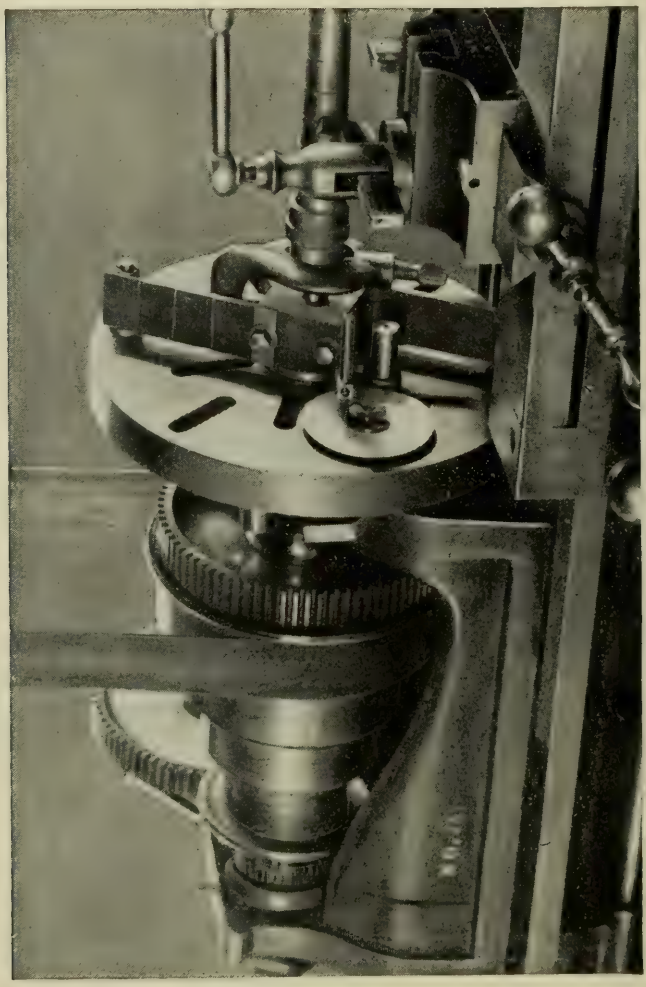
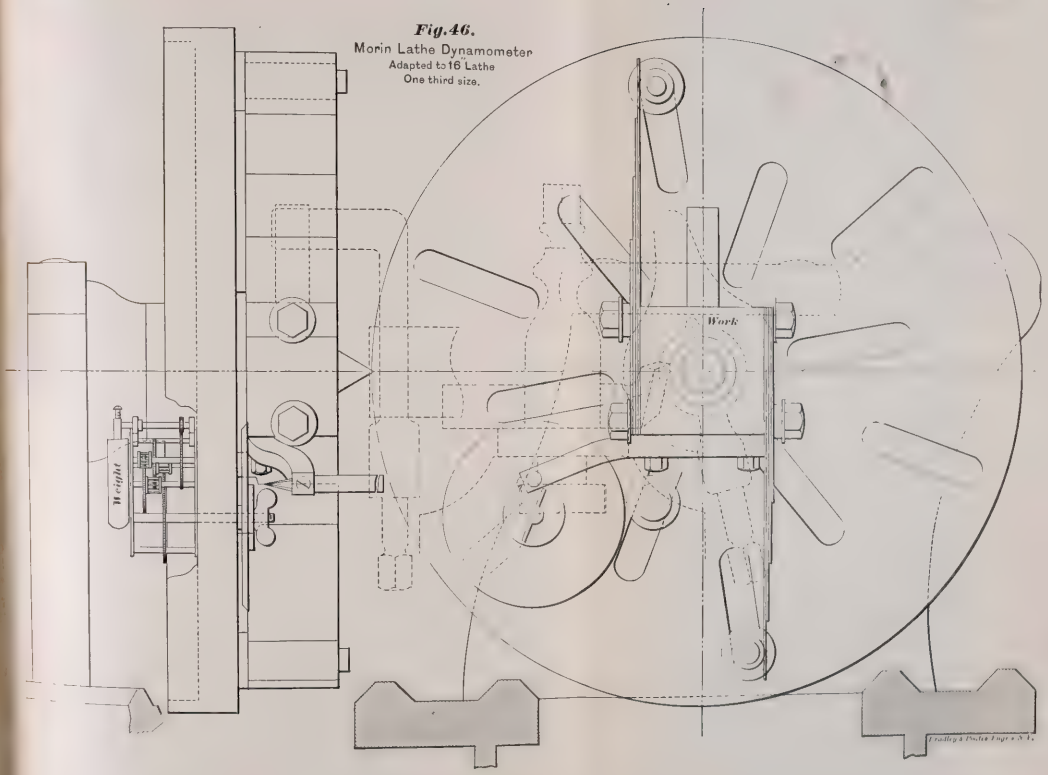


FIG. 47.

brake used in the calibration of the instrument had a lever arm of 24 inches. The calibration curve is shown in Fig. 48, the same being the average of all observations, of which a complete set was taken for each of five rotative speeds of the spindle, ranging from $7\frac{1}{2}$ to 58 revolutions per minute. The speed

Fig. 46.
Morin Lathe Dynamometer
Adapted to 16' Lathe
One third size.



seemed not to affect the results. Figs. 49 and 50 show cards obtained for the calibration at the speeds of $7\frac{1}{2}$ and 58 *r.p.m.*

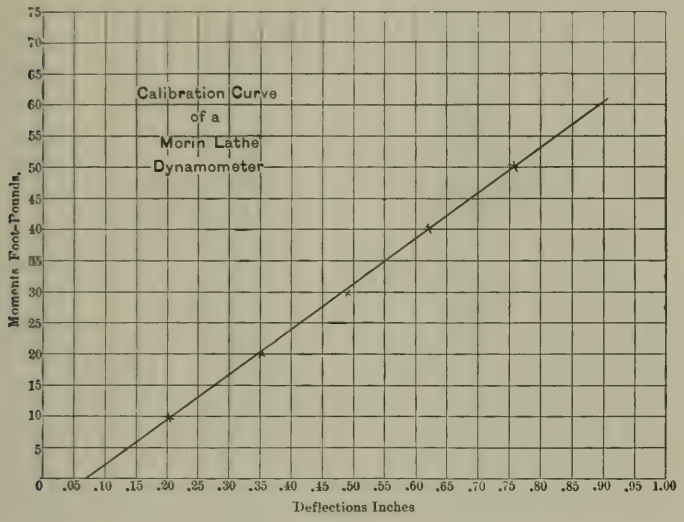

Calibration Curve
of a
Morin Lathe
Dynamometer
Moments Foot-Pounds.
Deflections Inches
0 .05 .10 .15 .20 .25 .30 .35 .40 .45 .50 .55 .60 .65 .70 .75 .80 .85 .90 .95 1.00
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

FIG. 48.

respectively. The increment of load in the calibration was 5 pounds. The equation of the calibration curve is

$$Y = 73X - 5.14,$$

where Y represents foot-pounds and X represents height of card measured from the datum circle.

Experiments were made upon cast-iron cylinders, $2\frac{1}{2}$ inches diameter and 10 inches long. These were reduced by roughing cut to 2 inches. A card for such a roughing cut is shown in Fig. 50. Three rates of feed are provided by the lathe, and these were used in the experiments. For each rate of feed cards were taken for depths of cut varying from $\frac{1}{32}$ inch to $\frac{1}{4}$ inch, or $\frac{5}{16}$ inch by $\frac{1}{32}$ inch. The amount of metal turned off was ascertained by weighing before and after the cut. The cutting speed, reckoned from the initial diameter of 2 inches, was constant, about 30 feet per minute, the spindle making 59 *r.p.m.* Figs. 52 and 53 are cards for one series of these experiments. The irregularities are due to varying quality of the metal, and to stoppage between the cuts. Despite such irregularities, however, the average ordinate was readily obtained for each card. The results of the experiments are as follows:

Depth of Cut. Inches.	Feed per Revolution. Inches.	Weight in Pounds. Metal Removed per Cutting Foot.	Pounds Pressure on Tool Point.
$\frac{5}{16}$	0.0083	0.0065	466.8
$\frac{9}{32}$	.0083	.0059	413.9
$\frac{1}{4}$	.0083	.0055	378.7
$\frac{7}{32}$	.0083	.0047	343.5
$\frac{3}{16}$	.0083	.0042	299.4
$\frac{5}{32}$	.0083	.0037	255.4
$\frac{1}{8}$	.0083	.0032	237.8
$\frac{3}{32}$	.0083	.0025	184.9
$\frac{1}{16}$	.0083	.0015	140.9
$\frac{1}{32}$	.0083	.0010	61.6
$\frac{1}{4}$	.0128	.0084	642.9
$\frac{7}{32}$	.0128	.0080	590.1
$\frac{3}{16}$	.0128	.0076	537.2
$\frac{5}{32}$	.0128	.0061	510.8
$\frac{1}{8}$	.0128	.0053	440.4
$\frac{3}{32}$	.0128	.0040	369.9
$\frac{1}{16}$	.0128	.0030	229.0
$\frac{1}{32}$	.0128	.0011	105.6
$\frac{1}{4}$	.0172	.0113	731.0
$\frac{7}{32}$	.0172	.0103	651.7
$\frac{3}{16}$	.0172	.0092	607.7
$\frac{5}{32}$	.0172	.0072	537.2
$\frac{1}{8}$	.0172	.0056	413.9
$\frac{3}{32}$	.0172	.0046	343.5
$\frac{1}{16}$	.0172	.0031	255.4
$\frac{1}{32}$	.0172	.0016	132.1

In Fig. 54 the above results are plotted. It will be noted that all of the observations are located on or near the straight line $O\ A$ passing through the origin. The equation of $O\ A$ is

$$Y = 75566\ X,$$

in which Y represents tool pressure and X pounds of metal removed per cutting foot. The tool used was a diamond point having the form shown in Fig. 46.

From the above we may deduce that at the cutting speed of 30 feet per minute, and with the tool used in these experiments, it takes a tool pressure of 41.6 pounds to remove one pound of cast iron of average quality such as was here used per hour, and a heavier duty demands greater tool pressure in proportion to that duty.

The maximum tool pressure recorded was 731 pounds. At this point the belt slipped somewhat.

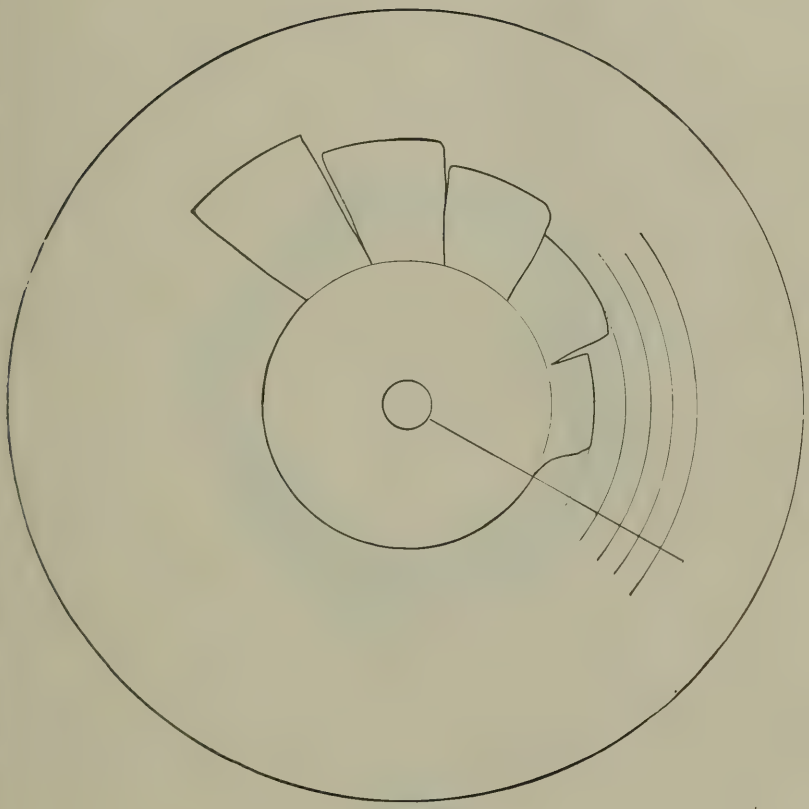


Fig. 49.

Fig.50

Fig. 51.

Fig. 52.

Fig. 53.

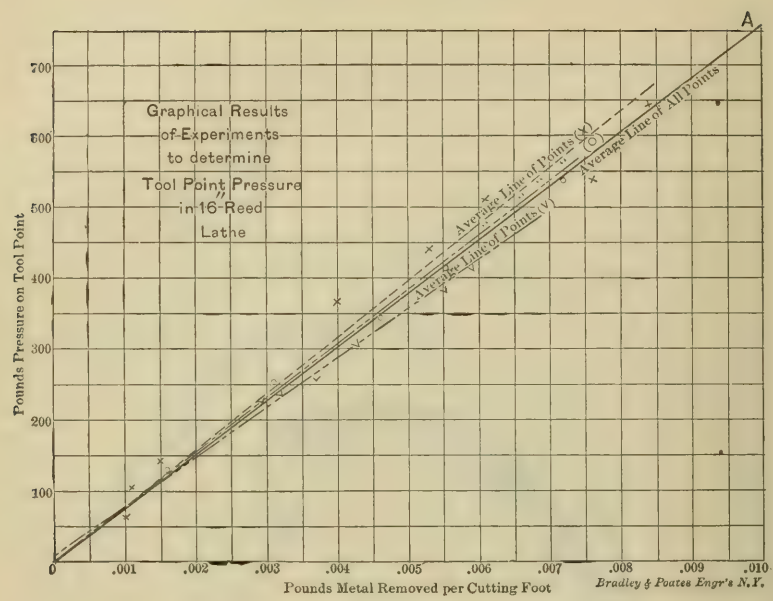

A
Graphical Results of Experiments to determine Tool Point Pressure in 16-Reed Lathe
Average Line of Points (V)
Average Line of Points (O)
Average Line of All Points
Pounds Pressure on Tool Point
Pounds Metal Removed per Cutting Foot
Bradley & Poates Engr's N.Y.

Fig. 54.

DISCUSSION.

Mr. Oberlin Smith.—You perhaps have all heard the old story of the boy who was looking on very anxiously at the other boy eating a big apple, and who, upon asking for a promise of the core, received the reply, "There isn't going to be any core." This illustrates the idea I have about the strains in lathe-beds. There'll not be any worth speaking of in a really good lathe—that is, in comparison with the strength that, incidentally, resists them. It is not necessary to provide for them if the lathe-bed is designed as it should be—in the shape of a *chunk of inertia*, so to speak. Some years ago I introduced the terms "anvil principle" and "fiddle principle," in contradistinction to each other, as applied to the framework of machine tools. I hoped at the time that I had started out in a modest way as a missionary, but whether there have been many converts from the heathen, I do not know. I think my work may have done some

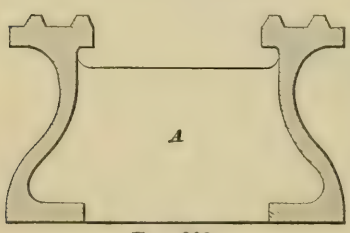


Fig. 202.

good, but, judging from the pictures of lathe-beds in this paper, which I believe show modern tools, and which my sketch, Fig. 202, somewhat represents, I should say this lathe was meant to illustrate the fiddle principle exactly, and that its bed makes a very nice design indeed for a sounding box. I have drawn a cross-girt at *A*, not shown in the original. There is, however, but a slight improvement wanted in this bed to make it good and solid. I suggest that the designers alter it somewhat in this manner [sketches in central section shading at *B*], as it now appears in Fig. 203. That now makes an excellent lathe-bed—with the one exception that the chips will not fall through. As a sacrifice to this convenience, however, it might possibly be made in this way [sketches in section shading at *C* and *E*], as I now make it appear in Fig. 204, with a slot *D* through the middle. [Laughter.]

What I particularly want to impress on people's minds is that all our machine tools are still enormously light in their stationary parts. Of course we must have the moving parts comparatively light in certain cases, but I do not see any reason why in all our smaller lathes a bed something like this shown in Fig. 204 should not be made. Take a 16-inch lathe: the cross-section I have added inside is from 60 to 80 square inches in area. At a maximum figure of 20 lbs. per inch, or 240 lbs. per foot of length, an 8-foot lathe would have less than a ton more metal than usual. We may assume that in making castings of this kind, where people have their own foundries, they can add iron inside such a casting for about a cent a pound, and with less trouble in moulding and pouring. Thus a matter of twenty dollars extra on a lathe worth three or four hundred dollars, seeming ridiculously small when we consider the whole life of the lathe of twenty or thirty years, makes the tool very much more efficient throughout its career. Alluding again to the anvil which, if I remember rightly, my friend, Mr. Porter, once spoke of in connection

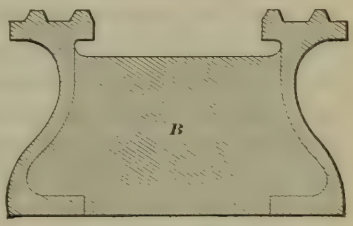


FIG. 203.

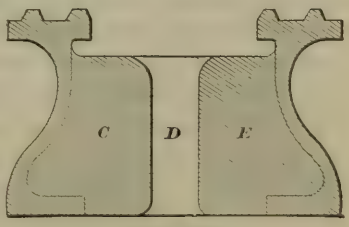


FIG. 204.

with machine tools before I got to comparing anvils with fiddles and so forth, I will illustrate with a case I have in mind, of a friend of mine who bought a number of automatic screw machines, weighing about 700 lbs. each, for making small machine and set-screws. They were working quite successfully, when a sample machine of like design, but weighing twice as much, was tried. It worked so much more efficiently that they threw away all the others. They tried another one weighing about double again, nearly 3,000 lbs., and the consequence was that the second ones were thrown out, and the third lot are doing such excellent work that they have entirely paid for themselves. The question of strains which distort machine-tool members is, in general, a very important one. I fully appreciate the trouble which has been taken in making the experiments mentioned in the paper before us. They are ingenious and beautiful, and ought to be carried on as long as we have our present lathes. Neither do I blame the lathe makers for trespassing upon musical instrument industries. It is purely a commercial matter. The people who design these lathes do so because they are requested to by their customers. Not many of them would be willing to pay another twenty dollars for a filled-up bed, because they are still heathen. When we get such beds as these in Figs. 203 or 204, with such an enormous excess of mere strength, we won't need to talk about their distorting strains, because they'll not distort—to speak of. After setting our anvil to absorb injurious vibrations, we, of course, want to provide against the thing settling out of a true plane, even to a slight degree, on account of being four-legged. I fully appreciate Prof. Sweet's idea that such tools should stand on three points. It is the only right principle. We all know that planers and lathes are very apt to go right into a twisted position as soon as we set them on a floor. It is mentioned in this paper that a lathe-bed is stiffer when fastened to the floor than when loose. That is making an old wooden floor do service as a part of the machine, and is all right if the floors would only stay where they are put. But floors won't stay anywhere in particular, and therefore you never know where your lathe is. With this anvil-like bed, however, we need not consider the vagaries of the floor at all, especially if we Sweet-ize it by putting it on three points. The principle of putting a good broad base to the legs at both ends, with one fastened to the bed and the other pivoted to it,

seems to me the ideal way of supporting a lathe. Three rigid legs, terminating in three feet upon the floor, is not so good a construction, as it lacks stability laterally. A bed mounted thus, and with the extra ton of iron in it, will stand all the strains we can possibly put upon it, and far more than the work would stand without being torn to pieces or breaking the tool down; and this without there being any of the deflections mentioned in the paper to a degree worth speaking of. There is another kind of deflection—the sagging in the middle of a long lathe-bed supported at its two ends. There was formerly a lathe in the market where this was provided for in the way shown in front view in Fig. 205, with a truss rod, *FF*, under the front and back edges. It seems very scientific indeed to make a bridge truss of the thing—or would, if there were nothing to cope with but downward stresses. Another lathe of the bridge style has come into the market with the bed swelled downward in the middle, as in Fig. 206. This is much more sensible than the other; but why not fill it down to the line *GG*, and get a simpler shape, together with a lot more vibration-absorbing inertia, under the head-stock, where it is wanted?

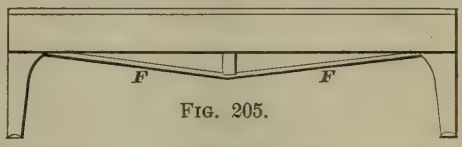


Fig. 205.

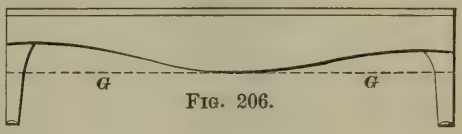


Fig. 206.

Mr. W. S. Rogers.—Mr. Smith has told a story. Probably I can tell one. His lathe pictures remind me of something I had not thought of for ten years. About that time I was trying to sell a lathe to a customer. There were several of us trying to sell one. The others talked workmanship and the advantage of their machines over the one I was trying to sell. I talked weight. My customer wanted a good heavy lathe, and he must have it. When I found he was wanting a good heavy lathe, I found a builder who built a "heavy" lathe. He would ask the others: "What does your lathe weigh?" They would say 12,000 lbs. Then he would come to me.

"What did you say your lathe weighed?"

"Eighteen thousand pounds."

"And it is a good stout lathe?"

"Undoubtedly; look at the weight of it. You want a heavy machine—there it is."

"Well, they want about five hundred dollars more for their machine than you do."

"I know it; I am selling you the stuff cheap."

He bought it. He bought it on its weight. I didn't tell him that the shears were not straight. I didn't tell him that the carriage would turn taper without any set over. I didn't tell him that he had one of the best radiators to keep his shop warm on a cold day. I have never seen it since. I never went back, and he wrote me not to come. Here is what I like about Mr. Smith's ideal lathe. This summer, in our shop, we have been putting in some new machinery, and I have been studying the lathe question carefully. We have now some modern tools. But we made a mistake. This fall we had to increase our radiators. If we could only have had those lathe-beds solid and got them warmed up, what coal we would have saved! It is a nice plan; I like it. Of course that great big solid lathe-bed would not sag down. Take a lathe-bed 20 feet long, and make it solid as that section shows: I would like to know how many cross ties we would have to borrow from the railroad company to prop it up.

Then there is that extra twenty dollars for iron, and it would cost about forty dollars more for labor to get that great mass of pig-iron carted around the shop and foundry. Look at the freight. Sometimes the builders have to pay that. If you are filling orders to a railroad they usually ask you to prepay the freight. I do not think I would approve of that part. If we had a lot of those heavy masses on the fourth floor, in case of a fire they would smash all the light furniture below. I would like rather to have them come down easy. If that idea works correctly, I do not see why we cannot build our bridges and turntables on the same plan.

Mr. Oberlin Smith.—If Mr. Rogers compares the bed of a lathe to bridge building, he is doing what others are doing who are suffering from the trouble I spoke of. What we want is the anvil principle—the mass of inertia there to keep the thing from starting into vibrations.

*Mr. G. W. Bissell.**—Probably a fiddle, as usually constructed, has greater strength and stiffness than could be obtained by any other arrangement of the same amount of material which would meet the acoustic requirements.

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* Author's closure, under the Rules.

Why not then apply the "fiddle" principle to machine-tool design?

If we do this in the present case—viz., Mr. Smith's lathe-bed—the result would be a bed of box section, which, with much less metal than Mr. Smith's design calls for, would give the same strength and much greater stiffness.

While admitting that machine sections should be made heavier than they commonly are, the writer believes that the metal may be and often is disposed very unfavorably when the "anvil" principle alone is carried out. There is a difference between a lathe and a steam-hammer. Let us compromise between the two principles as applied to lathe-bed design. Follow the fiddle principle by employing the box section, and the anvil principle by adding metal, putting it where it will do the most good.

DXIII.*

TESTS OF A PUMP RECEIVING SUCTION WATER UNDER PRESSURE.

BY R. VAN A. NORRIS, WILKESBARRE, PA.

(Member of the Society.)

THE following experiments were made in April, 1892, with the view of determining the advantages of the plan of feeding water under pressure to a direct-acting pump over that of drawing the water from a receiving well. The circumstances were as follows:

The borough of Nanticoke, Pa., is supplied with water from Harvey's Creek, a small stream tributary to the Susquehanna, the water being conducted through mains from a dam some two miles up the creek, and reaching the Nanticoke Water Co.'s pumping station with a piezometric head of about 60 feet when the pipe is flowing about 1,000,000 gallons per day. Up to the above date the water had been discharged at the pumping station into two receiving wells (Fig. 55), and thence pumped into the town mains by two duplex Gordon and Maxwell pumps, 22-inch steam cylinders, 12½-inch plungers, 16½ inches actual stroke. It was suggested by Mr. J. H. Bowden, the chief engineer of the company, that the pressure of water in the mains could advantageously be used in feeding the pumps. Accordingly one well was thrown out of use, and the connection shown in Fig. 55 put in, consisting merely of an 18-inch pipe connecting the suction of the pumps to the inlet from the main and extending across the No. 1 well, with a 10-foot length of 18-inch pipe standing vertically as an air chamber, to obviate any danger to the pumps from water ram. In this air chamber, and extending to the bottom of the tee to which it was connected, was a movable screen for removing any floating material from the water. This screen is readily removed from the bottom for cleaning.

Both pumps, it will be seen, were arranged to draw from

* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

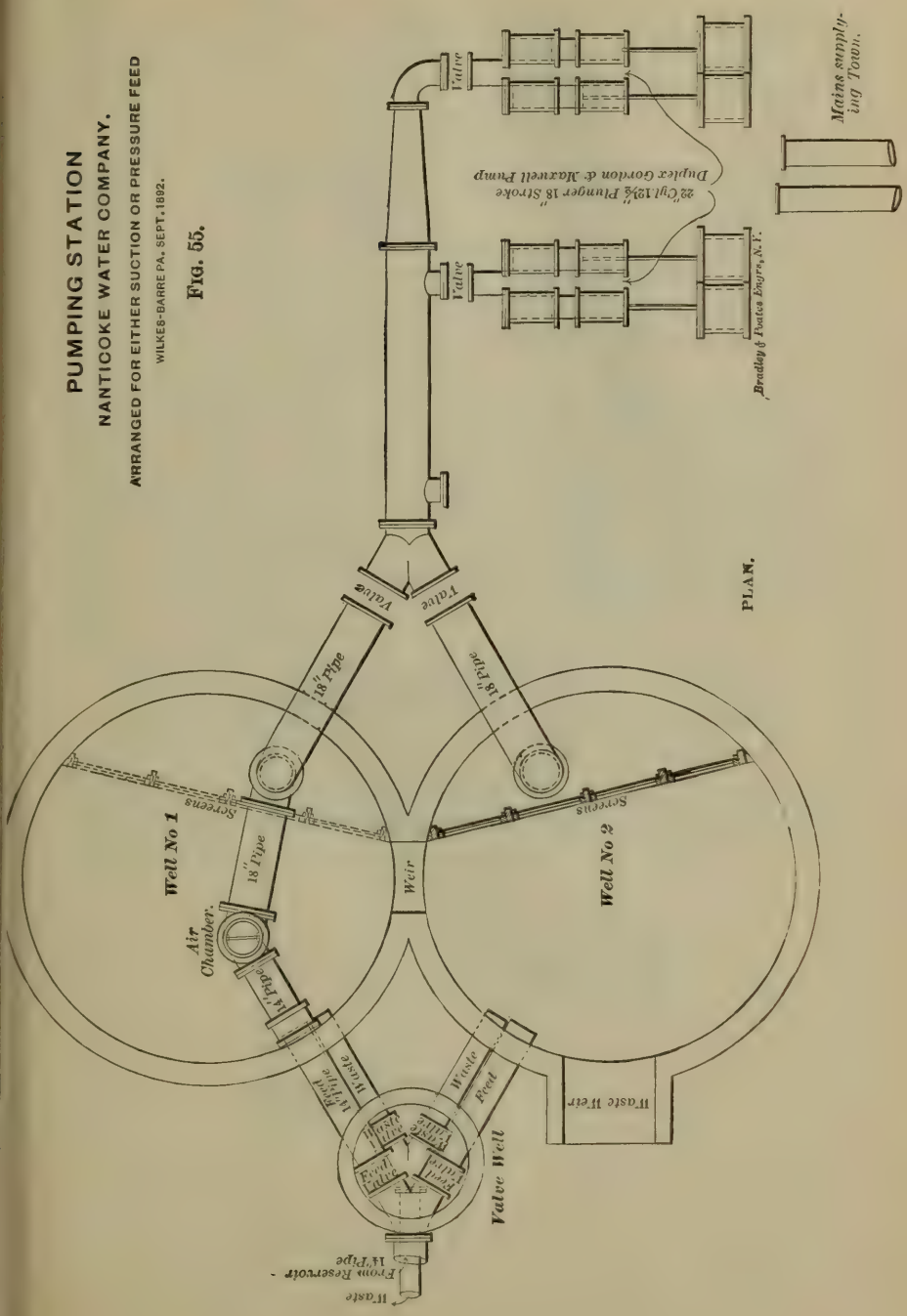
PUMPING STATION
NANTICOKE WATER COMPANY.
ARRANGED FOR EITHER SUCTION OR PRESSURE FEED
WILKES-BARRE PA. SEPT. 1892.
Bradley & Dodge Engrs. N.Y.
22" Cyl. 12½" Plunger 18" Stroke
Duplex Gordon & Maxwell Pump
Valve
Valve
Mains supplying Town.
PLAN.
Valve
Valve
18" Pipe
18" Pipe
Screens
Screens
Well No 1
Well No 2
Weir
18" Pipe
Air Chamber.
14" Pipe
14" Pipe
Waste
Waste
Foot Valve
Foot Valve
Waste
Waste Water
Valve Well
From Reservoir
14" Pipe
Waste

Fig. 55.

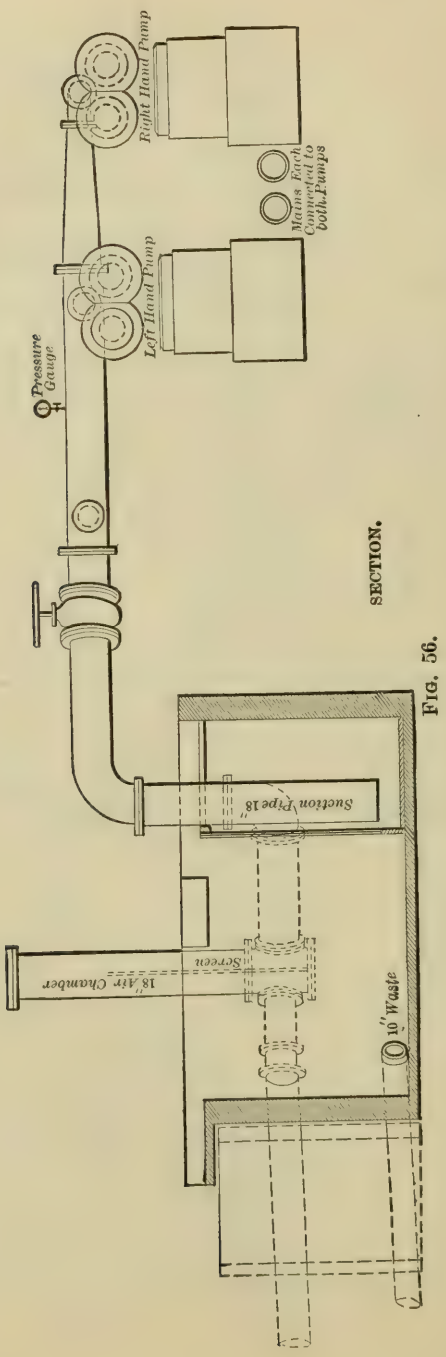
Right Hand Pump
Mains Each Connected to both Pumps
Left Hand Pump
Pressure Gauge
SECTION.
Suction Pipe 18
Screen
18" Air Chamber
10" Waste

FIG. 56.

either well, so that no stoppage was necessary in making the change; and when it was desired to change from suction to pressure, or *vice versâ*, all that was required was the opening of one valve and the closing of another.

The pumps are supplied with steam from the Susquehanna Coal Co.'s boilers at their No. 2 shaft, distant about 150 feet, through a 6-inch wrought pipe, and just before the pressure was turned on they were both making 25 single strokes of each plunger per minute, sucking their water from No. 2 well. As soon as the valves were changed their speed increased to 33 strokes, without change of steam valves, and they appeared to run much more smoothly.

The accompanying indicator cards were taken on April 9th by Mr. Bowden and the writer, and the results in the following table calculated from them. Four cards were taken from each end of each cylinder under each condition, and the results in the table are averages from them. The pressure in the "suction" pipe was determined by a pressure gauge in the position shown, read at time of taking each card. Cards were taken under the following conditions:

Suction from well, 50 strokes of each plunger, cards 1 *S.* and 1 *W.*
Suction from well, 25 strokes of each plunger, cards 2 *S.* and 2 *W.*
Pressure from main, 50 strokes of each plunger, cards 3 *S.* and 3 *W.*
Pressure from main, 25 strokes of each plunger, cards 4 *S.* and 4 *W.*

They seem to show that about 90% of the gauge pressure in the main was utilized, and that the resulting saving in steam calculated from the cards was about 20%.

Indicator Cards from Steam and Water Cylinders.

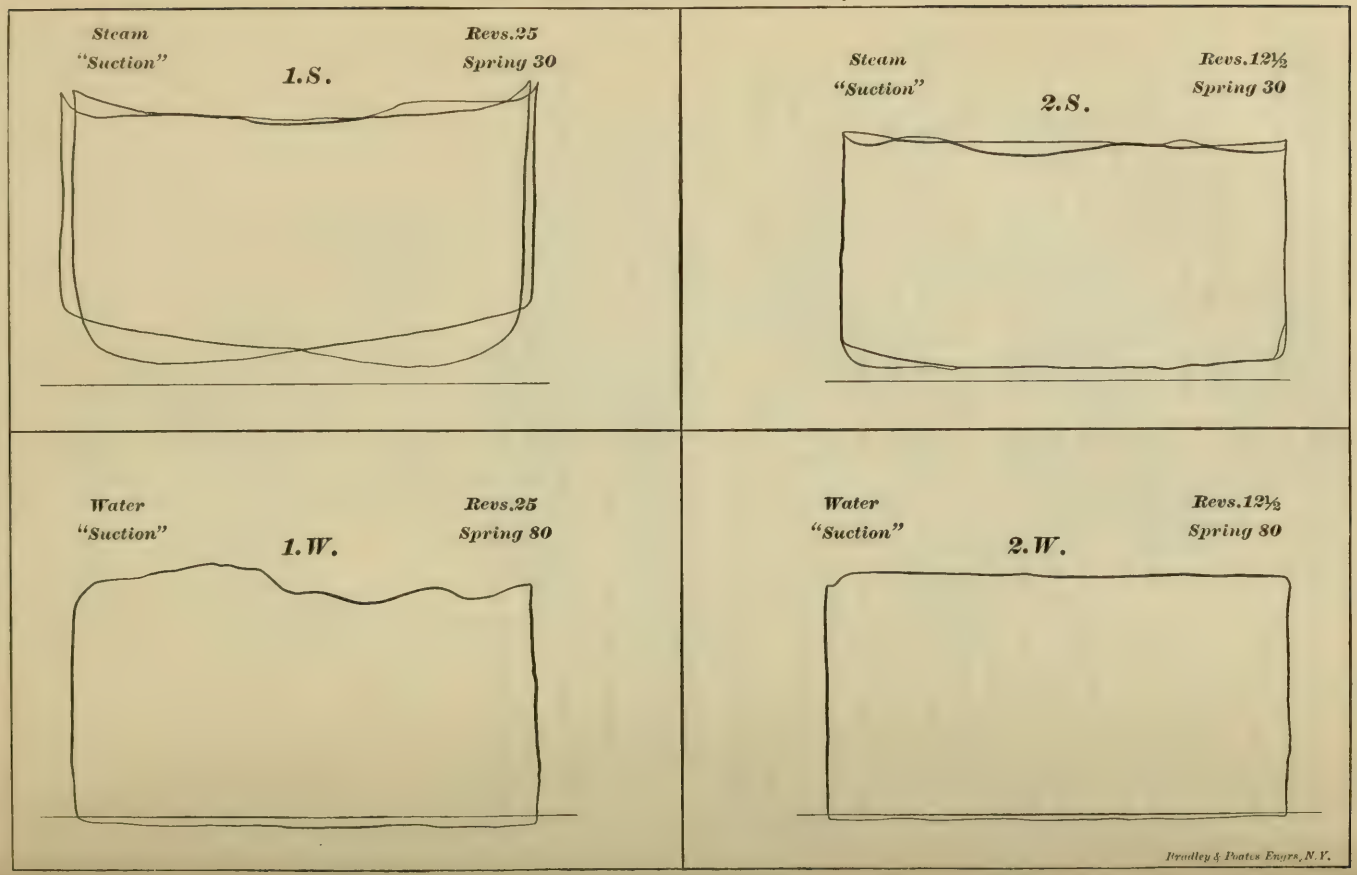

FIG. 57.

FIG. 58.

Nanticoke Water Co's Pumps. Suction and Pressure Feed.

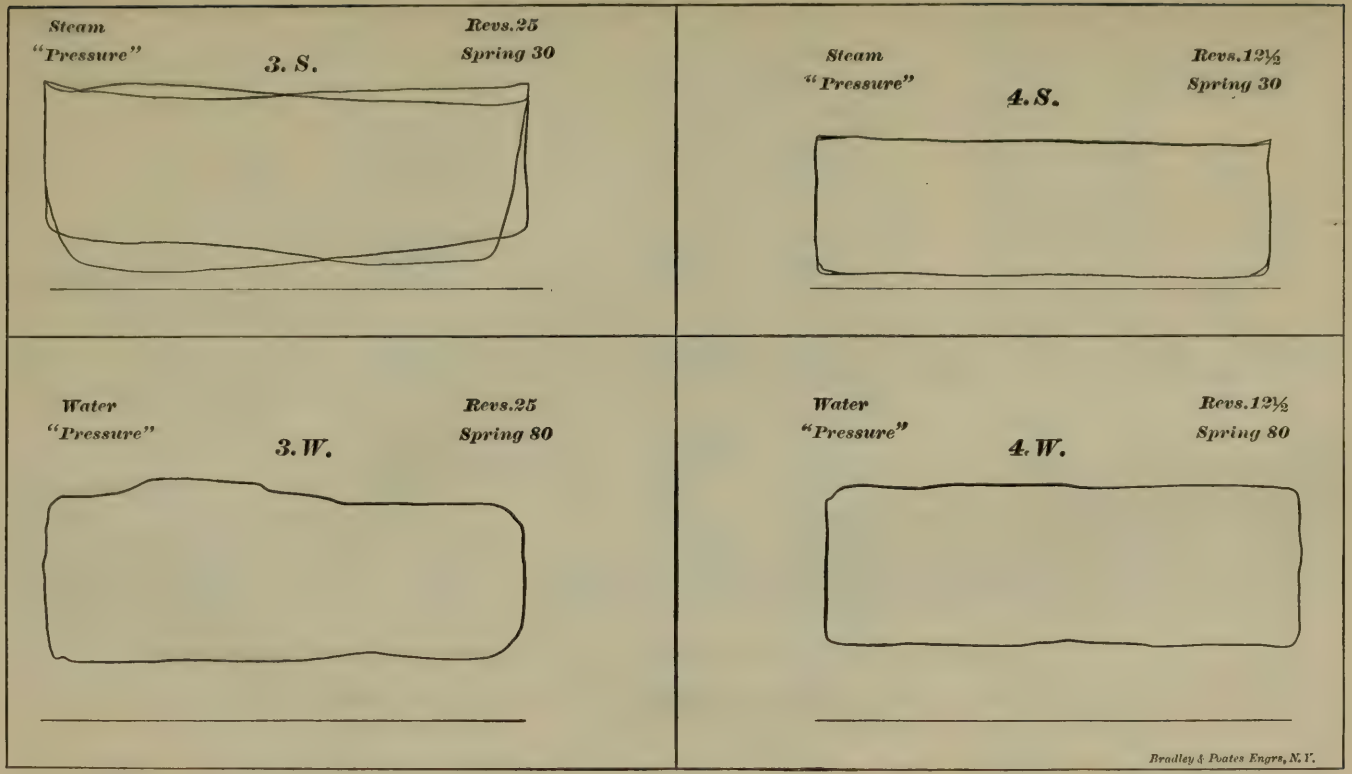

FIG. 59.

FIG. 60.

TESTS OF NANTICOKE WATER CO.'S PUMPS, APRIL 9, 1892.

PUMPING FROM WELLS AND DIRECT FROM SUPPLY MAIN. TESTED BY J. H. BOWDEN AND R. VAN A. NORRIS.

Gordon and Maxwell Duplex Plunger Pumps. 22-inch steam. 12½-inch plungers. 16½ inches actual stroke.	Condition of working.	Single strokes each plunger per min.	Average mean effec. pressure, steam.	Average steam consumed per hour.	Average pumping pressure above atmos., lbs.	Average pressure in tail pipe, lbs.	Average back pressure on plunger, lbs.	Per cent. pressure in tail pipe utilized.
Right-hand pump	Suction	50	36.1 lbs.	3,156 lbs.	93.5	$-3.\frac{1}{10}$		
	Pressure	50	24.75 lbs.	2,420 lbs.	99.6	+30	$25\frac{3}{10}$	$85\frac{1}{10}\%$
	Difference		11.35 lbs.	736 lbs.				
			$31\frac{5}{10}\%$	$23\frac{3}{10}\%$				
	Suction	25	33.4 lbs.	1,358 lbs.	91.9	$-3.\frac{3}{10}$		
	Pressure	25	23.1 lbs.	1,060 lbs.	97.3	+32	$29\frac{4}{10}$	91%
	Difference		10.3 lbs.	298 lbs.				
			$30\frac{8}{10}\%$	$21\frac{3}{10}\%$				
Left-hand pump	Suction	50	33.9 lbs.	2,912 lbs.				
	Pressure	50	25.25 lbs.	2,369 lbs.				
	Difference		8.65 lbs.	543 lbs.				
			$25\frac{5}{10}\%$	$18\frac{6}{10}\%$				
	Suction	25	32.4 lbs.	1,314 lbs.				
	Pressure	25	23.3 lbs.	1,060 lbs.				
	Difference		9.1 lbs.	254 lbs.				
			$28\frac{1}{10}\%$	$19\frac{3}{10}\%$				

No measurement of the water pumped under the two conditions was attempted, as it went directly into the supply pipes; but the pumps appeared to work more smoothly and to keep the stand-pipe level more constant under pressure than when sucking.

The suction valves of the pumps were provided some years ago with springs to make them seat promptly, and these were not altered by the change in method of feed.

These experiments were made simply for our own satisfaction, and, while not carried far enough to be of exact quantitative value, it is hoped that they will be of some interest, sufficient to elicit discussion.

DISCUSSION.

Mr. A. Faber DuFaur.—Suction under pressure was used at the Washington aqueduct years ago. The Washington aqueduct had to supply the high-service reservoir at Georgetown at a higher level than that under which the water comes in, and there was placed a duplex pump in the abutment of the Rock Creek bridge on the Georgetown side. The pumping cylinders received the water under pressure. Instead of using steam, the power cylinders were supplied with water under pressure also, so that one-half of the water was rejected, and the other half was pumped up to about twice the height. This was done before the war. The pump worked very well.

Mr. H. DeB. Parsons.—I have examined a good many water works in the West, and I find that as a class the Western engineers are objecting to using suction under pressure. They give no other reason than that the pressure will lift the valves and keep them lifted when the stroke starts to return, thereby causing a loss. I examined the works of a large city in southern Illinois, not long ago, where the supply came from three reservoirs on a hill above the pumps, and the water was brought down through a pipe into a catch basin in front of the pump house, and the suction of the pumps merely dipped into that basin. They had there a good opportunity to connect with the reservoir, giving a suction under pressure, and, if there was a gain, to have utilized it; but they went to the expense of digging this catch basin and lining it up and making it look pretty, for the simple reason of getting rid of the pressure on the under side of the valves. Of course, the pressure in the mains to the

city always greatly exceeded the pressure of the water from the reservoirs. Otherwise it would have been a gravity system. But I have found a number of places in the West where this has been done. The head has been thrown away—if there is any advantage in using it—simply, as they say, to prevent the valve from being lifted by the pressure.

Mr. Jos. C. Platt.—It seems to me that the question to which Mr. Parsons has referred is an illustration of what is so frequently met by engineers. The men in charge of work of that sort are apt to follow the rule of thumb which they learned in their early days, and are not willing to follow and benefit by the advice of others who have gone further than the rule of thumb practice. They fail to benefit by utilizing power or useful effect which is at hand and ought not to be thrown away. The experience which Mr. Parsons has reported to us is like that which has happened to all of us, where, as mentioned in the paper, foremen or superintendents of erection are opposed to innovation, and where they are sometimes forced to acknowledge that there may be something in theory which can be worked into good practice. I take it that nobody would approve of throwing power away, and an opposition to the saving spoken of in the paper would seem to be due to an acknowledgment on the part of the practical men that they do not know how to use what they have, and is a confession of their own weakness rather than anything like an insistence upon the necessity of letting power go to waste.

Mr. Parsons.—I made those few remarks with the hope that some pump manufacturer or some one interested in the sale of pumps would answer me. What I meant to have brought out clearly was the fact that pumps are sold and knowingly sent to places where a suction under pressure can be used, and yet the builders or sellers of the pump give no intimation to the consumer that it would be an advantage thus to connect his pump. If there is any advantage, I should think the competition of the trade would make the manufacturers take advantage of it so as to give an apparently greater efficiency to their pump over other places where there is no head in the suction main.

Mr. F. M. Wheeler.—I did not intend to say anything in the way of discussion on this paper, but Mr. Parsons' remarks bring me to my feet. I think he is quite correct. As a rule, the pump manufacturers take too much for granted. They usually

think that any one who purchases a steam pump understands how to connect it up properly. It is quite surprising, however, to find how few really know how to connect a steam pump to get the best results, especially where the supply of water comes to the pump under a head. I usually take the trouble to follow up each case, and see what the purchaser intends to do with the pump, in the matter of its location and piping connections.

Regarding the use of suction chambers, I consider them of

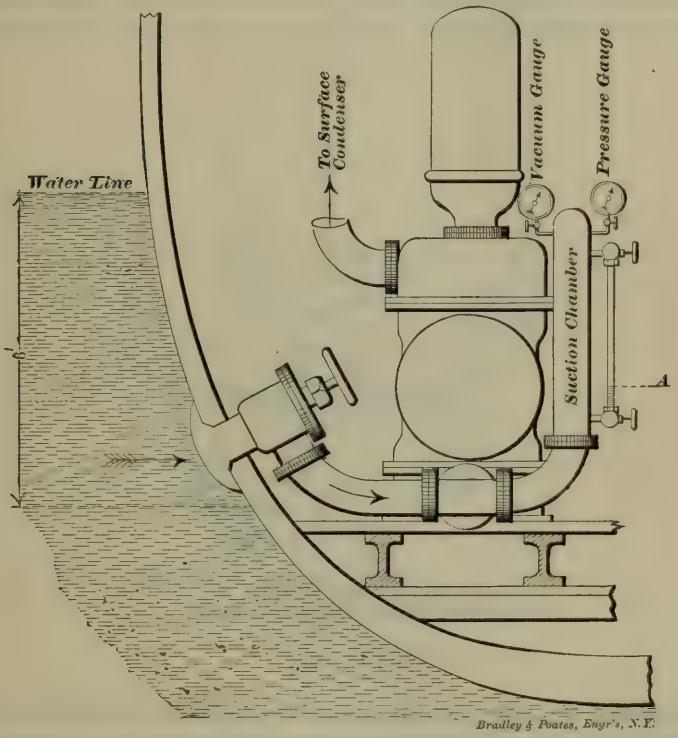

Fig. 188

great importance. An interesting case I have in mind, showing the great advantage of the suction chamber where the supply came to the pump under a head. It was on the United States cruiser *Dolphin*—the trial trips of which vessel you have all heard so much about. As a rule, on board ship the pumps are placed below the water line. The circulating pump on the *Dolphin* is 26 inches diameter, and located five or six feet below water line. This pump is a direct-acting horizontal steam pump

of the Blake type, attached to and operating two single-acting air pumps. In order to make this circulating pump run noiselessly I considered necessary to attach a suction chamber—this feature would also make the pump run smoothly, and help to secure the full value of the head of water on the suction—and to locate it as shown by this sketch (Fig. 188).

One engineer remarked that there was no advantage in putting on any suction chamber, as it would fill up solid, because there was a pressure of water in the suction pipe, and thus this would defeat the very object desired. I was very much amused

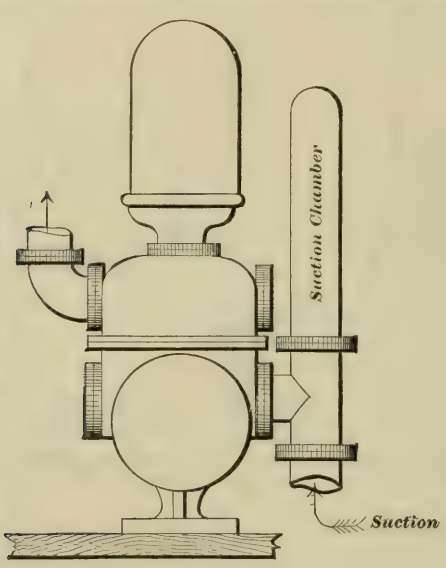

Fig. 189

at this and other opinions expressed, and out of half a dozen engineers and mechanics there was not one who anticipated correctly the conditions which actually prevailed in the suction chamber. As the sketch shows, I placed on the side of this suction chamber a glass water-gauge about 4 feet long; also at the top of the suction chamber I put a light spring pressure gauge and a vacuum gauge. The pressure on the discharge of the suction pump was about 6 lbs., and, as indicated, the surface of water outside of the vessel was about 6 feet above the suction nozzle of the pump. As remarked, it was thought that the suction chamber would fill solid with water. As a matter of

fact, however, when the pump was working the water never rose higher than about 6 inches from the lower end of the glass water-gauge, at which place (see point *A* and Fig. 188) it oscillated (at each stroke of the pump) about 6 inches. Alternately, the gauges would show about 5 inches vacuum and 2 to 3 lbs. pressure respectively on the vacuum and pressure gauges. This demonstrated the suction chamber to be of great value, because it not only relieved the impact of the water column against the water piston at each stroke, but it also allowed the head of water on the suction to be fully utilized. In other words, the

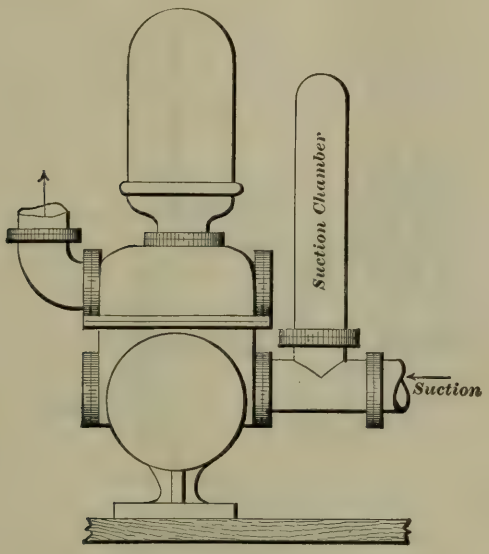

Fig. 190

water in the suction chamber moved up and down about 6 inches, and we had alternately vacuum and pressure, thus proving the importance of its use. When the pump was first operated they partially closed the sea-cock. Of course, I protested, and demonstrated that by so doing they were throwing away just so much power by decreasing the head of water. With the sea-cock wide open, the strokes of the pump were increased from 10 to 15 per minute with the same pressure of steam. I have found very often in marine-engine practice they begrudge the room necessary for a properly arranged suction chamber, preferring to screw down on the sea-cock in order to prevent the "water

hammer" in the pump. Of course, you can make a pump run quietly by letting in air through check valves in the water-cylinder heads, but that practice is against the efficiency of the pump. I consider the value of a suction chamber greater than that of a regular air chamber where a pump works under light pressure, and if I could not have both, I would take the suction chamber in preference, every time!

Suction chambers are also very important in the case of long suction pipes, but judgment must be used in placing them.* The nearer the suction chamber is to a pump the better—at the

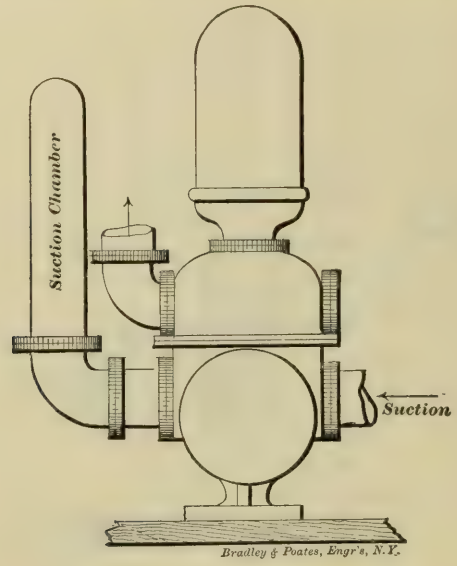

Fig. 191

same time it can be so placed that it becomes of little or no use. I have a case in mind where the pump had nearly 400 feet of 14-inch suction pipe, with a vertical lift of a few feet only. In taking the order for this pump, I looked carefully after the matter of suction chamber, which it was understood would be arranged as shown here by Fig. 189. Some months later, in visiting the place, I was not surprised to hear them complain of the noise made by the pump, as I found they had not properly

* Here I wish to observe that the suction chamber shown on the suction pipe of the pump plant at the Nanticoke, Pa., water works was placed at the wrong end of the suction pipe.

located the suction chamber, which they placed on the suction pipe as shown here by Fig. 190. They gave as an excuse that they could not approach the pump with the suction pipe on a vertical line, the foundation of the building preventing. In other words, they had to come into the pump-room with the suction pipe horizontally, and thought it was all right to place the suction chamber at right angles to the pipe, as shown. As you can readily understand, the column of water travelling in a direct line to the pump was never deflected into the suction chamber; there was, therefore, no impact or cushion in the suction chamber, and it became of little or no value. Fig. 191 shows how the trouble was corrected, the air chamber being placed on the opposite side of the pump with a proper elbow, thus receiving the impact of water over and across the water barrel of the pump. After this change the pump worked perfectly smoothly.

If pump makers would always take the trouble to recommend suction chambers, and pipe fitters use a little care in placing them properly, there would be less complaint about the jar and noise of the pumps, to say nothing about wear and tear.

Mr. Gus. C. Henning.—I should like to give an explanation to Mr. Parsons—an explanation of what he saw out West. I saw the same thing, but I do not care to mention the city where it was, because we might know who was the engineer in charge. The pump problem out West is not always an engineering problem. It is originally a political problem. When it has been decided how much money is to be expended on a scheme, with everything that belongs to it, such as a reservoir park and granite steps to lead up to it, and a big suction chamber, and everything of that sort, then a man comes in and says, I can put in such a maker's pump, and there is so much to go all around. (Laughter.) So when the engineers are called in, the man's pump may not work under pressure, on account of the valves, as Mr. Parsons says. Some valves do not work properly under pressure. But that is not the question at all. After it has been decided how much money is going to be spent on the plant—the more the better—then bids are called for. If it were considered merely as an engineering problem, increased efficiency of the pump due to lifting the water against a lesser head would mean a smaller pump—and therefore less money. If the engineer considers utilizing the water pressure available to lessen the load on the

pump, that means a still smaller pump—less money again; less to go round. The only thing which can be done is to get the highest priced pump and then put it in operation under the conditions imposed after the engineer has said what it is going to do. But I do not think the engineer is asked to do anything until they have decided certain preliminary matters not known to the engineer. Most engineers know full well that pressure, of course, except in certain constructions of valves, will add to the efficiency of the pump. That is simply a theoretical problem, irrespective of the practical question—Who is to put the pump in operation?

Mr. Norris.—It has been pointed out to me very neatly that we put our air chamber in the wrong place, but I have only to say that that was the most convenient place for it, as an air chamber also contained our screens, and that we did not know as much as we do now. The air chamber as placed does, however, do some good. Of that there is no doubt in my mind, because the water-ram, as shown by our pressure gauge, was very slight, only some 4 or 5 lbs., and the air chamber had two or three gauge cocks in it which showed that it stayed partly full of air and that the water level oscillated. As to the valve seating, I think the water cards show that they do seat as well with pressure as with suction. One of the other mining companies in our region had a worked out seam for a sump, but it was about 10 feet above their pump. They were so thoroughly convinced that they could not run their pump with water under pressure that at an expense of about $1,000 they blew out a chamber in the solid rock below their pump, and ran the water to it from their main sump.

DXIV.*

NOTES ON THE REFRIGERATION PROCESS AND ITS PROPER PLACE IN THERMODYNAMICS.

BY GEORGE RICHMOND, NEW YORK CITY.

(Member of the Society.)

SINCE the Transactions of this Society already contain a number of papers treating the subject of Refrigeration from various points of view, the *raison d'être* of these notes seems to call for some explanation.

This will perhaps be best afforded by stating their origin: Some twelve years ago a client, provided with a copy of Clausius and an assortment of refrigeration conundrums, such as occur only to imaginative inventors, presented himself to the writer, with an order for the demolition of the second law of thermodynamics in the interest of a scheme for the dissipation of capital.

This order, it is hardly necessary to say, was never filled; it was, indeed, quite sufficient work, with the means at hand, to find intelligible answers, on elementary principles, to the conundrums in question. In pursuit of this object, what appeared to be a striking analogy with the complete statement of the refrigeration process was found in the complex cycle devised by Clausius for the discussion of the second law. He gives, moreover, as his final statement of this law, an expression for heat identical in form with that for work rendered so familiar by application to the indicator diagram. By using this for the representation of heat transfers, in place of the work diagram, the chapter on equivalent transformations becomes much more intelligible.

Hence, it seemed that the refrigeration cycle might be made the starting point for the development of thermodynamics, with the obvious advantage that we attack the practical problems connected with the heat engine, and its reverse, at an earlier stage. In the course of several years a great number of such

* Presented at the New York Meeting, November, 1892, of the American Society of Mechanical Engineeers, and forming part of Volume XIV. of the Transactions.

problems were brought under the writer's notice, and treated by the method of transfers, as the only one by which the results could be rendered intelligible. Quite recently, by another accident of business, the subject was again forced upon him, and in overhauling the mass of notes which had accumulated, it was thought they might contain some suggestions worthy of consideration.

It will be apparent that the mere statement that a refrigeration machine is a heat engine reversed, is insufficient explanation when, as in the absorption system, neither can be identified. A more fundamental principle is necessary, viz.: that of equivalent transfer without loss of energy or availability. The refrigeration process is then found to be only one case of this more general principle. The term heat transfer, as used in this paper, refers primarily not to the transfer from one body to another, but to the transfer on the scale of availability. Such a transfer can be effected in two ways only; viz.: by a transformation of a portion of the heat into work (which can be neither more nor less than the total available energy due to such change of position), or by the spreading of the heat over a larger mass. The tendency to do this marks the characteristic difference between heat and more familiar forms of energy. An attempt is made to show, on elementary principles, that this fact leads to, and indeed requires, the adoption of an independent variable having the attributes of the so-called entropy. In practice this diffusion of heat is studied under the form of transfers from one body to another. Every such transfer is accompanied by scale transfer, and the sum of these represents the loss in availability. Our attention, therefore, may be almost exclusively directed to such transfers, and the estimation of their dynamic significance.

The fact that the scale of availability is a function of the temperature, gives the real value to the expression

$$Td\varphi,$$

without which the areas it represents would be comparatively meaningless. The usual method of reaching this conclusion, and hence the adoption of the Thompson scale, representing both temperature and availability, is familiar to all who have studied this subject. The suggestion that the equivalent transfers as exemplified in the refrigeration process enforce, and

might be used to establish this conclusion (since in this case the total heat involved is an invariant) is one of the points submitted to the criticism of the reader. The form of these notes precludes the idea of logical completeness, but while, using the layman's privilege of greater freedom than could be accorded to *ex cathedra* statements, presentations are made which are not entirely satisfactory, even to the writer, it is thought that the advantages of the graphical method of representation merit careful consideration. Though first suggested by an American professor,* and probably more or less used by individuals, the literature on the subject in this country could hardly be more scanty.

We are familiar with the representation of work by an area, and since heat is energy convertible into work, it must also be

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* Prof. J. Willard Gibbs, Trans. Conn. Acad. Arts, etc., Vol. II., Part 2. These notes were finished too late for the San Francisco meeting, and subsequently the writer's attention was called to the new edition of Cotterill's *Steam Engine* (Spon, 1890), by which it appeared that the $T\varphi$ diagram had received considerable attention in Europe. In rewriting the latter part of these notes the literature of the subject was examined as far as opportunity permitted, and the writer acknowledges his obligations to Mr. Macfarlane Gray—through Cotterill not having found the original papers referred to—and to G. Hermann, *Die graphische Behandlung der mechanische Wärmetheorie* (Berlin, 1885).

The facts appear to be that Clausius (or possibly Rankine) first expressed heat energy in terms of suitable coördinates, but being wedded to analytical methods, failed to see their availability for graphical representation. This was pointed out by Gibbs, and subsequent writers contented themselves with referring to his article as showing that other coördinates than pv could be used to represent heat relations. The characteristic equation of a substance being the surface $f(p.\ v.\ t.) = 0$, we may study it by projection on either of the three coördinate planes. Of these three the p, v. plane on which areas represent the work done by the substance was most attractive, since such areas could, in many cases, be traced out by the substance itself acting through a mechanical device such as the indicator. When we take $T\varphi$ as coördinates, our attention is no longer directed to the physical properties of bodies under the influence of heat, but to heat as a form of energy, of which φ is the measure of quantity and T the symbol of identification on the scale of availability. For the first practical application to the study of the steam engine, we must refer apparently to Macfarlane Gray or Hermann. It was thought advisable, however, to present the subject in the form in which it first occurred to the writer, which involves the idea that the second fundamental equation of Clausius may be used for developing the theory of thermodynamics, reserving the first for physico-thermal relations, thus inverting the usual order. The advantage of this is in a great measure due to the superior simplicity of the graphical representation of the second equation, but more than this is implied. It will be found, for example, that many analytical relations are arrived at by a more direct path.

capable of being represented by an area. It is not, indeed, difficult to form areas proportional to the quantities of heat coming under consideration; the utility of these will, however, depend on the choice of the coördinates. In the present case the reasons for the choice of those used will be more apparent after their use in presenting thermodynamic relations has been shown.

The work done by a machine is always less than the work delivered to it. The doctrine of conservation of energy teaches us to look for this missing work in some form of energy, and accordingly we find substantially the whole of it in the form of heat, as in the equation:

$$W = W_1 + H$$
$$W = \mu W + H \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Or there is a transfer of a certain fraction μ of the work, accompanied by a transformation of the remainder into heat. It is the object of practical mechanics to make the value of μ as large as possible, and that of H the smallest possible; in fact, the tendency to transformation requires constant watchfulness.

We do not commence the study of mechanics by an investigation of the properties of bodies and the theory of friction. On the contrary, by assuming the maximum value conceivable for μ, namely, 1, which makes $W = W_1$, we acquire, as a preliminary step to a more complete study of the whole phenomena, certain useful information as to statical relations.

Of a given quantity of heat H, a certain portion can be transformed into work. That is,

$$H = H_1 + W$$
$$H = \mu H + W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Our object in this case is to make μ as small as possible, in order that W may be the greatest possible. The question naturally arises, Why cannot we make $\mu = 0$, and transfer all the heat into work? There is no difficulty in the preceding case in making $\mu = 0$, or transforming all the work into heat. At this point two courses are open to us: we may discuss the value of μ, and endeavor to find its limits as derived from some hypothesis as to matter and energy; or we may provisionally assume that μ has a fixed maximum value for each set of conditions, and defined by them.

By the second method it is possible to acquire a certain familiarity with the phenomena of transfer and transformation of heat, which, thus treated, may by analogy be termed thermostatics. Many of the problems presenting themselves in the practical application of thermodynamic principles may be usefully discussed in this manner, and it is an open question whether a student might not obtain a firmer hold on the principles of the science, by a short course on these lines, before entering upon the study of the thermo-physical properties of the agents used to effect the transformation. The agent, it must not be forgotten, is merely a practical contrivance; the laws governing the transformation were indeed arrived at through the study of the agent, but these once determined, it is no longer necessary to the conception of the relation between heat and work.

Whatever notions we may have of energy and work in general may be invoked to our aid in this connection. Nothing can be more definite than our conception of work, as a quantity. We produce it and buy and sell it by measurement. Displacement —relative displacement—the invariable condition, which (other things being equal) measures the work, will naturally form one of our coördinates for a work area. To the other we give the name Force, etc., but it will be found that our conception of force as a quantity is derived from the measurable, and therefore intelligible quantities—work and displacement. It resolves itself into a statement of the rate of doing work during displacement. Without displacement no work and no definite idea of force, pressure, etc.

Energy being defined as capacity for doing work, whether or not all or any part of that energy is available depends upon how we are situated in relation to it, and also on our mechanical resources. The limitation may, therefore, be essential or accidental. A bushel of wound-up watches represents on the aggregate a respectable amount of energy. Yet without opening the cases we can suggest no means of utilizing any part of it. An iron ring surrounding the earth and revolving with the same velocity might be said to embody a vast amount of energy—we could not utilize enough of it to break a spider's web. The inability to produce relative displacement is accidental in the first

case ; we can conceive no process like that of opening the watch-cases which would render the energy of the ring available.

Let the ring, however, move a little faster, we can transform enough of its energy to bring it back to its original rate, which indeed we should have considered its total energy, but for the knowledge of the motion of the earth.

The mere statement that energy consists of so many foot-pounds or kilogram-meters gives us no information as to its availability. A thousand diagrams of the same area would each represent the sum total of our knowledge. We need some symbol of identification which shall tell us in what relation we stand to the energy, as determining its possible displacement producing quality.

For example, consider a case of potential energy (Fig. 62); the

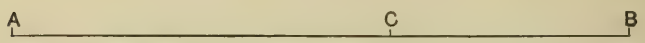

FIG. 62.

energy of the body, B is proportional to its mass and some function of its distance from A ; *i.e.*, in the equation

$$E = \mu E + W,$$

μ is a function of this distance. If we suppose the energy of B at different positions easy of measurement, we may measure distance conventionally, such that a unit distance is gone over for each unit of work done by B. Such a scale of distance would be different from our ordinary notions of length, but is easy to imagine. In this case,

$$\mu = \frac{d_2}{d_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where d_1 and d_2 are the distances of C and B from A,

$$E = \frac{d_2}{d_1} E + W. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$W = \left(1 - \frac{d_2}{d_1}\right) E. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

the latter expression being the work done in passing on our conventional scale from B to C. It is plain that this work is a

fixed quantity; we can never change the position without transformation of this energy, and *by doing this work the body can be brought back to its initial position.*

We have assumed the mass of B constant. Let us now suppose that the mass may vary. If the energy is to remain constant, the distance of B must vary so as to preserve this equality. If to this we add the further supposition that there is constant tendency for energy to distribute itself over larger masses while preserving its amount intact, we have an interesting case; for B of itself will move up to C, by which action the available energy is constantly decreased, while the total energy remains unchanged. In the first case we were sure that when B arrived at C we had transformed the total available energy into work; at present we are in doubt. This doubt may be resolved in the following manner:

Set up a rectangle (Fig. 63) on which the height AB represents on our conventional scale the distance of B from $A = d_1$, while $AC = d_2$ $Bb = Aa$ representing on any suitable scale the mass of B initially. From equation (5) if the mass remains constant the rectangle Bc is the work obtained, and Ca the remaining energy at C.

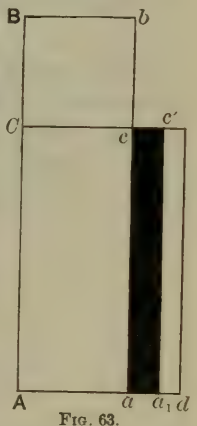

Fig. 63.

If, however, the body of itself moves to C by distribution of the energy over greater mass, then the rectangle $Cd = Ba =$ this constant energy.

Obviously the rectangle $cd = Bc =$ the energy which might have been transformed into work.

Under these circumstances cd is termed the dissipated energy. What is really dissipated is not the energy, but the availability.

Since the supposition is, that we can measure the energy of the body, we are now in a position to determine how much of the available energy we have really lost. If, when B arrives at C, it has the energy Ca^1 we know that the portion ca_1 has escaped transformation. The mass has increased by the amount cc^1, the lost availability is

$$d_2 \times cc^1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

We cannot now bring back the body to its initial position by

the expenditure of the work obtained, viz., $c'd$. The statement that a transformation process is *reversible* is evidently equivalent to saying that there has been no dissipation of energy, or that we have obtained the maximum value of μ. The terms "*perfect*" or "*reversible*" are, therefore, synonymous as applied to an engine for transformation.

Further,

$$BC = BA + AC \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

BA representing a positive transformation of all the energy of B into work, and AC a negative transformation of a portion of this work into energy.

But in order that the linear equation ($6a$) may represent energy proportional to the lines, the widths Bb Cc must be equal. This, then, is another criterion of perfect transformation.

We have assumed that the amount of energy in the body B is proportional to the mass of matter involved and not influenced by the kind of matter. If the contrary be true, then we cannot take mass as one of the coördinates of energy; we require to know the *energy capacity* of each kind of matter. If we represent this by c we might take as our other coördinate of energy the product cm. If, however, c varies and is liable to take on discontinuous values, we may be driven, as a last resort, to define the second coördinate as the quotient of the energy by the first.

$$\frac{E}{D} = \chi$$

$$E = D\chi = D\left(\frac{E}{D}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

On the face of it this seems merely an identity of no practical utility. It may happen, however, that the ratio $\frac{E}{D}$ or χ can be discussed apart from the absolute values of E and D; indeed, such a principle is of frequent application, even in elementary mathematics.

The theoretical relation between the mass of the body B and its energy becomes a condition when we pass to heat energy. There is a constant tendency for heat to distribute itself over greater mass, and thereby descend in the scale of availability.

Moreover, the heat capacity is different for different kinds of matter.

As regards the scale of availability it may be remarked that temperature is a general term for all symbols by which heat is identified. Without assigning any absolute meaning to the term we may call our scale of availability the temperature scale.

$$\mu = \frac{T_2}{T_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$W = \left(1 - \frac{T_2}{T_1}\right) H \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

If we can find a body such that its heat-mass * and its heat capacity remain constant, we can determine our scale of availability; cm remaining constant, equal quantities of transformed energy will mark equal degrees on the scale, and if we can find the total energy, or the fraction of the total energy, represented by one such transformation, we obtain the zero point of the scale. Bodies very nearly answering to these conditions are the so-called permanent gases.

But, if c has discontinuous values, we must take some such quantity as the χ above mentioned for the independent variable; calling it entropy, and writing it φ, we obtain

$$dH = T d\varphi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Hence,

(1) The entropy of bodies of the same kind of matter (in the same state of aggregation) varies as their masses.

(2) In bodies of different kinds of matter it varies as their heat capacities.

(3) In any bodies whatever it varies as their heat, however defined.

(4) In all cases it varies inversely as the temperature.

Combining the first, second, and fourth statements, the rate of increase of entropy for increase of temperature

$$\frac{d\varphi}{dt} = \frac{cm}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10\,a)$$

When the value of c becomes discontinuous, we must fall back upon the more general statements—(3) and (4).

* By constant heat-mass is meant absence of diffusion over greater mass by conduction, radiation, etc.

If $c = \infty$, then energy can be stored up in the body B without removal on the scale. Such energy is termed latent heat, and in the present state of our knowledge, the amount for any given substance must be ascertained by empirical formulæ derived from experiment, aided by analytical relations. It is a popular error to confuse latent heat with untransformable heat, whereas it will be found that from it alone we obtain the full dynamic value. An agent performs its function of transformation by passing from B to C and back again. The return passage is effected by expending a portion of the work obtained from its first passage, and but for this isoscalar or isothermal storage and rejection of heat, these two quantities of work would be equal, and no useful result would be obtained.

The refrigeration process as an object lesson.—Viewed from the outside, an ice-making plant is seen to receive heat at one end, and deliver heat at the other. The fact that ice is its only product excludes the supposition that the heat has been finally changed into some other form of energy. We may consider the plant an unknown mechanism, enclosed within a chamber impervious to heat, except at such points as it is desired to introduce or withdraw it, and appropriately designate it a transformer.

Since, upon the whole, this transformer remains at the average temperature of surrounding objects, the doctrine of conservation of energy enables us to assert that it must deliver exactly as much heat as it receives.

Part of the heat it receives is embodied in a stream of water which leaves it unchanged, except that it acts as a vehicle for conveying heat out of the system. Since the heat thus introduced takes no part in the transaction, we may omit the consideration of it, for it would appear on both sides of our equation. The temperature of this water may conveniently be taken as the point from which the quantities of heat actually engaged may be estimated, and its amount may be supposed so large that it performs its function of a heat carrier without any great rise in its own temperature. Let H be the amount of heat introduced in the form of steam, and $-h$ the heat delivered in the form of ice, the latter being negative on account of the choice of our zero temperature, the heat imparted to the

water and delivered with it must be the difference of these, or $H + h$.

The object is to obtain the greatest amount of heat h with the least expenditure of heat H, and the fraction $\frac{h}{H}$ may be termed the efficiency of the transformer. This, however, is not strictly correct, for the value of this ratio will be found not to depend on the mechanism of the transformer, which, as such, is presumed perfect.

Upon what does the value of $\frac{h}{H}$ depend? If we were completely in the dark and left to experimental means, we perceive that the only direction in which we can produce variations is in changing the temperatures. We know, of course, what the result would be: that if the temperature of H were the same as that of the water, the action would cease, and the heat delivered would be identical with the heat received. Also, if we raise the temperature of H without increasing the quantity, we should find the quantity h also increased. On the other hand, if the transformer is manipulated so as to furnish h at a lower temperature, the quantity will be found to be smaller.

By instituting a sufficient number of experiments, we might find an empirical relation between $\frac{h}{H}$ and the different temperatures employed; that is, express its value as a function of the temperature.

$$\frac{h}{H} = f(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

However, the characteristics of heat furnish us with a clue to the rationale of the process. It is observed that heat passes readily from bodies of a high temperature to those of a lower, but that the reverse action never occurs unless under peculiar circumstances, with which the doing of work at some period or other will be found inseparable. Since we have no instance within our experience to the contrary, we may accept as an axiom that "*heat will not of itself pass from a cold body to a warmer.*"

But our transformer is a practical example of the passage of heat from a lower to a higher temperature, and also of the passage from a higher to a lower. Since the former, by our axiom,

cannot occur alone, and does not occur in the absence of the latter, the true relationship is that of cause and effect. The nature of the relationship is more apparent when we open the transformer and see an engine at work; and, accepting the fact that such engine is actuated by part of the heat energy received, we see that it supplies the work necessary to effect the transfer from a lower to a higher temperature. But the engine is not always present; indeed, it is evidently only an accident, for the delivered heat, in the form of ice and warm water, has the same capacity for work as the received heat in the form of steam and water. There is no loss of energy and no loss of availability; merely a transfer in the scale of temperature of one quantity of heat accompanied by the transfer of another in the reverse direction; such transfer may be, therefore, termed equivalent.

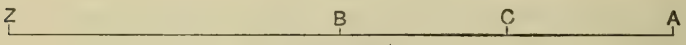

FIG. 64.

This may be represented by the configuration ABC (Fig. 64), a transfer of a certain quantity of heat from A to C being accompanied by a transfer from B to C, C being the neutral temperature of our heat receptacle. The configuration implies that by reason of its position at A a certain fraction (k) of the amount of heat can be converted into work. k will vary with the position of A, becoming smaller as it approaches C, where it is 0, and thereafter negative, indicating that work must be done to effect the transfer from B to C. Since temperature is an arbitrary symbol of identification, we may so choose our scale that distances on it shall be proportional to the work obtainable or done. If Z be the zero point, then $k = \frac{AC}{AZ}$.

The transfer from B to C cannot take place (by our axiom) without the expenditure of work or equivalent compensation. That from A to C can; indeed, on account of the characteristic tendency of heat to distribute itself, there is always a probability that the full dynamic value is not obtained. When it is, then:

$$\frac{AC}{AZ} \cdot H = \frac{BC}{BZ} \cdot h \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$^{*}\text{or,}\quad e = \frac{h}{H} = \frac{AC}{AZ}\cdot\frac{BZ}{BC} = \frac{T_1 - T_0}{T_1} \times \frac{T_2}{T_0 - T_2} = f(t). \quad . \quad . \quad (13)$$

This may perhaps be made clearer by a graphical construction. A quantity of heat H may be represented by a rectangle whose height AZ_2 is the temperature on our conventional scale, which, as previously shown, is practically identical with that of the air thermometer. The width may be of any convenient

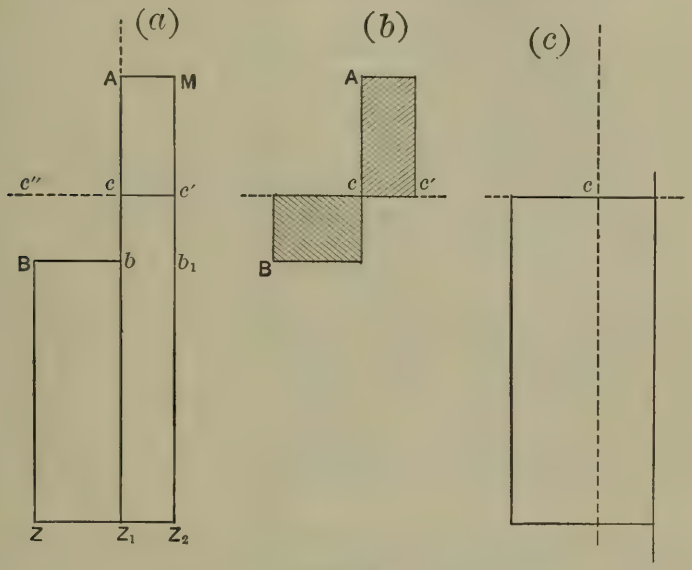

FIG. 65.

length. Similarly the quantity of heat h may be represented by another rectangle BZ_1 Fig. 65 (*a*), of which the height is its absolute temperature. The initial condition is indicated by (*a*). If the transformer consists of an engine and compressor, the operation represented by (*b*) is observable; namely, a portion $kH = Ac'$ is converted into work by the engine, which is

* e is evidently = cross ratio $CZAB$; if $-h = H$ this becomes the anharmonic ratio $ACBZ$. C, the point to which two equal quantities of heat can be transferred without loss of available energy, being the conjugate of Z, the absolute zero point of this latter can be found by construction. This is true of any form of energy for which a scale of availability can be found; if Z is at infinity, e = simple ratio ACB, which is practically the case for ordinary examples of the potential energy due to gravitation.

transferred as the equal work cB to the compressor, and expended in raising the heat h from B to C, being itself transformed into heat. The final result is that indicated by (c), in which all the heat is at temperature C. In the absorption machine the process of double transformation (b) is not recognizable; we may, therefore, use the former system to establish the necessary relations which must be equally true for both systems, for they must be independent of the actual per formance of the double transformation (b). For graphical construction it is convenient to have the same unit surface for heat and for work; accepting the ordinary unit of heat, our unit of work will be taken equal to it or 778 ft. lbs. To convert any of our results to the foot-pound notation, it is only necessary to multiply by 778. The areas Ac' and cB may be termed the dynamic values * of the heats H and h respectively, and the second law of thermodynamics may be thus stated in terms suitable for graphical representation.

If a unit of heat be represented by a rectangle of which the altitude is the absolute temperature at which it is taken, then a horizontal at any other temperature will cut off its dynamic value at that temperature. If this horizontal cuts the rectangle within, *the portion cut off represents the amount of work which can be obtained; if it cuts it* without, *the dynamic value is negative and represents the amount of work which must be done to change the temperature.*

Thus cc' is within the rectangle AZ_2 and Ac' is its dynamic value, but cc'' is without the rectangle BZ and $-cB$ is its dynamic value.†

The refrigeration cycle may therefore be split into two cycles; by the one the temperature of a body is reduced by converting a part of its heat into work; in the other its temperature is raised by doing work on it. One advantage of studying them together (apart from the obvious fact that they follow the same laws) is that neither can be considered alone without at some time introducing the other. Moreover, what-

* Throughout this paper the term *dynamic value* is used to indicate that portion of a heat area which is transformable into work, or the available energy.

† Considering AZ_2 and cZ_2 elemental rectangles, the areas swept out by AcZ are respectively the heat received, the heat rejected, and available energy. It will be seen that c can never fall to the left of AZ_1 and that when it falls to the right there is a loss of availability by rejection of transformable heat.

ever results may have been obtained by the investigation of the one may be applied directly to the other.

The equation of condition (12) may be stated in words—the dynamic values of the two quantities of heat must be numerically equal; that is, $Ac \times cc' = cb \times Bb$ or,

$$* \theta\varphi = \theta'\varphi' \ldots\ldots\ldots (14)$$

θ being the range of temperature Ac of H, and θ' that of h, while φ and φ' are the respective widths of the rectangles. This width which remains constant during the transformation is the entropy. If any hesitation is felt in using the term, then width may be retained; for having decided on a certain area to represent a unit of heat and chosen the scale for one side, the significance of the other side is fixed, by whatever name it is known.† Retaining the name, however, since the thing it represents is so simple, the vertical lines are isentropics and the horizontal isothermals. The temperature C in our process is identified as the temperature of the heat conveyer or the water supplied to the apparatus. There is an obvious advantage in making this as low as possible, for the effect of taking an isothermal below cc_1 would be to increase the area Ac of work obtainable, and diminish that of cB the work to be done. The height of cB being diminished, its width must be increased so as to make its new area equal to the new area of Ac' or the heat removed h is increased.

It is also plain by our axiom that C is the lowest temperature at which h can be discharged. It is not, perhaps, equally obvious that C' is the lowest temperature to which we can reduce H. But it will be found that even for the single cycle ACZ_1, a heat carrier called the agent is a practical necessity, which receives the heat to be transformed at A, and discharges the untrans-

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* The condition (14) may be more scientifically expressed thus—the sum of the available energy with respect to C must be 0,

$$\theta\varphi + \theta'\varphi' = 0,$$

remembering that the second term is negative.

† When the heat area is not a rectangle, entropy is the horizontal dimension, being the *projection* of the path, it is the same for all paths between two points. While the temperature scale measures the *proportion* of a given amount of energy which is transformable, entropy is a measure of the *absolute* quantity of energy transformed, hence the term ἐν-τροπη', *transformation* value.

formed heat preparatory to taking a fresh supply. If the transformation were continued down to the temperature b_1, additional work cb_1 would indeed be obtained; but in order to discharge the untransformed heat bZ_2, precisely the same amount of work cb_1 would have to be done.

Apparent contradictions of this statement will disappear when the cycle is completed, or the agent brought back to receive a new supply of heat. During the first trip around, our results may have been beclouded by the fact that the agent gave out some work at the expense of its own energy. This energy may usually be traced to work done upon it at some previous period, and will be eliminated after one trip around the cycle.

Dismissing for the present the consideration of the agent, many important questions may be investigated with our present knowledge of the relation of heat to work.

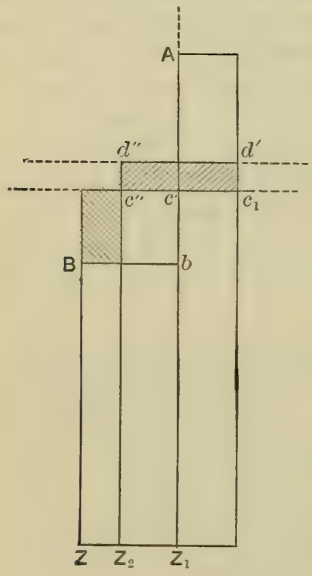

FIG. 66.

While it is desirable to have the temperature C as low as possible, it is frequently limited by the fact that the water serving as heat conveyer has to be purchased. In this case (Fig. 66) the temperature becomes $d''\ dd'$, and the available work Ad' instead of Ac'. Making bd'' equal to Ad', the refrigeration h is reduced from bZ to bZ_2 or in the proportion,

$$Z_1 Z_2 : Z_1 Z.$$

The point of greatest economy, therefore, is reached when such a temperature d is found that any further reduction by the purchase of more water would cost more than the extra refrigeration obtained.

Seeing that in some cases the temperature of the discharged heat is above that of surrounding objects, it has been imagined that a heat engine could be established to furnish additional work. Under the conditions supposed, this is indeed possible. The dynamic value of the heat $d'Z_2$ discharged at d is the shaded area $d''c'$ with respect to c, but it can be easily seen that this

area is equal to that of the shaded area Bc'',* indicating that if the temperature c were really available, the increased dynamic value would have been better employed directly in doing the additional refrigeration Bz_2.

When the transformer consists of an engine and compressor, we may economize in the quantity of the heat conveyer by discharging the untransformed heat of the power cycle in the air. By this arrangement we relieve the heat conveyer of the amount of heat cZ_2, but the available energy dc' is lost.

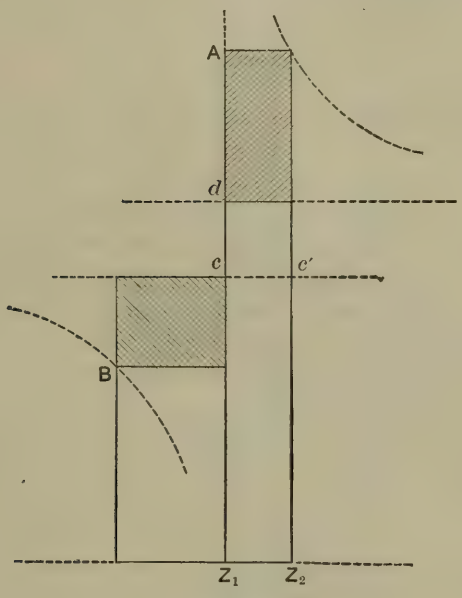

FIG. 67.

The equation of condition is still the equality of the two shaded areas (Fig. 67).

The process of refrigeration, as usually conducted, consists of the equivalent transfer of heat above considered. It is evident, however, that the necessary conditions would be conformed with by supplying the amount of work Ac' from any source whatever, as a water wheel, etc.

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* $Ac' = cB$
$-Ad' = -d''b$
$d''c = d''c.$
Adding

Given an amount of work, how much refrigeration can be effected with it? The graphical solution of this problem is shown in Fig. 69.

Let the rectangle cP represent the given amount of work at our disposal, say 1 H.P., or 42.4 of our work, or heat unit areas. Since we know only the area of our rectangles, namely,

$$\theta'\varphi' = 1 \text{ H.P.},$$

we can draw any number of equal rectangles in the angle c, and

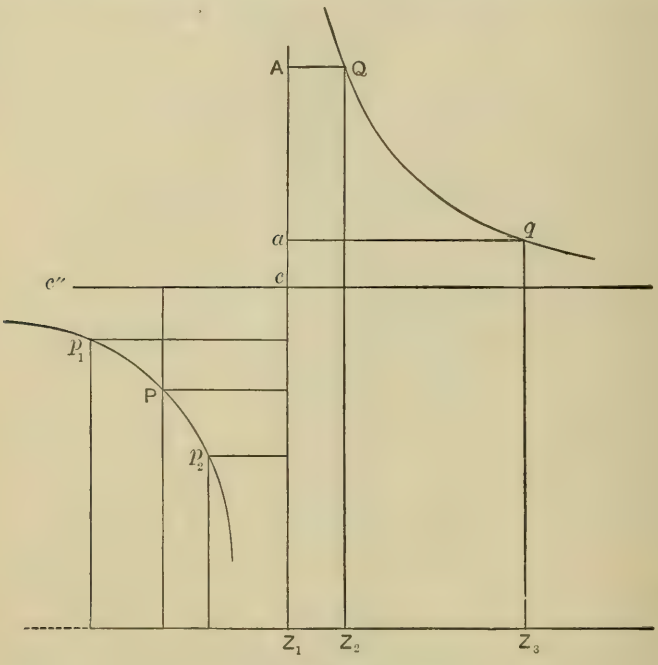


FIG. 69.

the locus of their opposite points P will obviously be on a rectangular hyperbola through P. For each position of P, as p_1, p_2, the refrigeration will be the rectangle p_1Z_1, PZ_1, P_2Z_1, respectively, diminishing progressively as the temperature is lowered, at which the heat is removed.

If in addition to the quantity of work we know the temperature at which the refrigeration is to be effected, it is only necessary to draw an isothermal through that temperature to meet

the hyperbola in p. The refrigeration obtainable is then the rectangle pZ_1.

The work necessary to perform a given amount of refrigeration at a given temperature is obtained directly from the definition of dynamic value (Fig. 65). Represent the refrigeration by the rectangle BZ_1, at the required temperature, and draw the isothermal cc_1, cutting the rectangle outside. Then cB is the necessary work.

In the power cycle (Fig. 69), if we desire to know how much heat must be expended to obtain a given amount of work W, construct the hyperbola Qq, such that

$$\theta\varphi = W = Qc = qc, \text{ etc.}$$

When the range of temperature is Ac, the heat required is only QZ_1; but when the range is ac, the heat required is qZ_1, and so on.*

Equivalent transfer of heat has been hitherto referred to as a refrigeration process, the reason being that the result usually aimed at in its application is the removal of heat from bodies, so as to reduce their temperature below that of surrounding objects. The name, indeed, having reference to the result only, is calculated to conceal the true nature of the process, for it is obvious the power cycle may be considered a refrigeration cycle, since it is so conducted as to lower the temperature of bodies by transforming a portion of their heat. On the other hand, the second cycle may be considered a heating process, since the heat of bodies is increased by the transfer to them of the removed heat, as well as of the heat equivalent of the work done.

Heating Process.—The equivalent transfer may therefore be conducted so as to be considered, on the whole, a heating process.

Suppose it be required to heat a body from temperature C to D by direct application of heat, and for that purpose we have a unit of heat at temperature A, represented by the rectangle AZ. By simple transfer (conduction, radiation, etc.), the heat applied at D is evidently $DZ_2 = AZ$, with a loss of work $= Ad$.

But by dynamic transfer the heat applied at D is DZ, being

* From this we see the compression system possesses greater elasticity than the absorption, for in the former we can use any range we choose for the power cycle, the two cycles being absolutely independent, which is not the case in the absorption system.

the rejected heat of a heat-engine working with the range of temperature AD, and the work obtained Ad may be used to raise another quantity of heat CZ_3 from temperature C to D. Thus, by the equivalent transfer process, we have applied at D a quantity of heat

$$d'Z$$

which is always greater than

$$DZ_2.$$

The reason is obvious. In the first place, the availability of the high temperature heat was dissipated; in the second case, there is no loss of availability. This latter fact is easily seen on the figure, for dc is the dynamic value of the heat $d'Z$, now at d, is equal to the dynamic value Ac_1 of the original heat AZ when at A. This application of the equivalent transfer appears to have been overlooked, and is commended to the attention of electrical engineers, for it is only by application of it in some form that electrical heating can be conducted with any degree of economy.

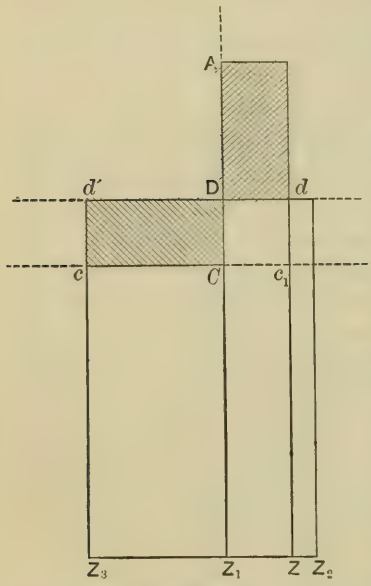


FIG. 68.

In electrical heating it is only the work Ad (reduced by successive transfers) which is available for heating purposes by transformation into heat. By suitable application this work would produce a heating effect DZ_3, which is not only very much greater than Ad, but (if a wider range AD is possible in the power cycle AZ_1 than is required by the circumstances of the reverse cycle) may be greater than the total heat expended in the power house, instead of a small fraction of it.

The idea of engine and compressor, one or both, is closely associated with the equivalent transfer process; they are absent, however, in the so-called absorption process, and, indeed, the

only condition is *conservation of availability*. We may not be at the end of our resources in complying with this condition, and means may be found of bringing high temperature heat within our reach without loss of availability, and without piling up our steam cylinders to attain the higher point.*

As already mentioned, the equivalent transfer may be split up into two cycles, and these are usually studied separately. The mechanism for effecting the transformation of heat into work being termed a heat engine, that of the reciprocal cycle, a reversed heat engine. In the heat engine the ratio of the transformed heat to the total heat has received the name, efficiency of the engine, and the reciprocal of this ratio is termed the efficiency of the reversed engine. In this view the efficiency of the whole process would be the product of these two. (Equation 13.)

The term, however, is equally misleading in both cases. The dynamic value of heat is a fixed quantity under given conditions of temperature and independent of the mechanism. The true efficiency of the latter is, therefore, the ratio of the heat it succeeds in transforming to the dynamic value or maximum amount which is transformable.

It is, perhaps, not unnatural—when we express the efficiency of an engine as a small fraction—to conclude that the engine is an inefficient contrivance. The misuse of the term is responsible for a flood of nonsense.† On the other hand, the efficiency of the reversed engine appears as an improper fraction, the absurdity of which is apparent, and has led to the analogous error of supposing that the amount of refrigeration obtainable should be the heat equivalent of the work expended.

By reason, then, of the imperfections of our methods, we fail to get the full dynamic value of a given amount of heat. We fail again in applying the work to obtain the full amount of refrigeration due to it. There is also a loss in transferring the work from

* The idea of a warming engine is as old as 1852, and due to Sir Wm. Thompson. (Cotterill, pp. 148 and 412.) In ignorance of this, the writer called attention to the fact in the Journal of Frank. Inst., 1886, "Refrigeration Machine as a Heater." His critics apparently were equally ignorant of the high authority behind it.

† The persistence with which this gush is forced upon the public by newspapers whose scientific articles represent paid advertisements, seems to indicate that there is a fund available for the propagation of error. The odium of this must fall on the beneficiaries.

the one cycle to the other, but this being a question of mechanics, and not of thermodynamics, will not be considered here.

Since heat can leave a body in two ways only, viz., transformation or transfer, any failure to produce the full dynamic value must be attributed to transfers. Every transfer must by our fundamental axiom be from a higher to a lower temperature, and must, therefore, mean a loss of available energy which is never recoverable in full. The work actually obtained, therefore, will be the dynamic value less the sum of the uncompensated transfers.

Since in all practical application of thermodynamic principles there occur a number of such transfers, it is important to estimate the exact dynamic significance of each, and, where possible, so conduct or modify the transfers as to produce the least dynamic loss.

Transfer of Heat.—Examples of heat transfers are exhibited in Figs. 70 to 79. From 70 to 75 the transfers are, positive, from a high temperature body S to a lower temperature body R. The last four are examples of negative transfer from a lower temperature to a higher temperature. Fig. 70 represents the ideal case in which the heat after transfer has the same temperature as before, and is, therefore, termed an isothermal transfer. In this case the dynamic value after transfer *by* is the same as the original BY, so that there is no loss of available energy by the transfer. Though this is an impossible case, it is a limiting condition which may be assumed in certain calculations.

In Fig. 71, the body S remains at a constant temperature; R is also maintained at a constant but lower temperature.

$$\begin{aligned} &\text{Dynamic value before transfer} = BY \\ &\quad\text{“}\qquad\text{“}\quad\text{after}\quad\text{“}\qquad by \\ &\text{Loss} = BY - by = pz_1. \end{aligned}$$

In all these figures the dynamic loss, or loss of availability, or dissipated energy (which are equivalent terms), is represented by the blackened area.

If φ_1 be the entropy of the heat area corresponding to S and φ_2, that of R, and T_0 the temperature Y, namely the lowest available temperature, then

$$pz_1 = T_0\,(ab - AB) = T_0\,(\varphi_2 - \varphi_1). \quad . \quad . \quad . \quad (15)$$

I. POSITIVE. ...ss of availability $= T_0 (\varphi_2 - \varphi_1)$.

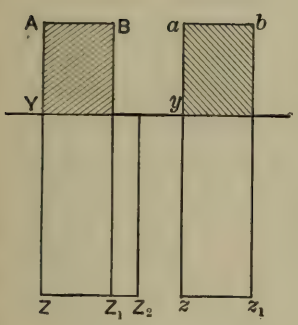
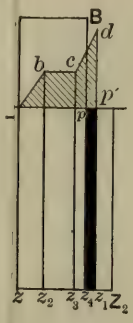


FIG. 70.

(1) Ideal isothermal transfer.



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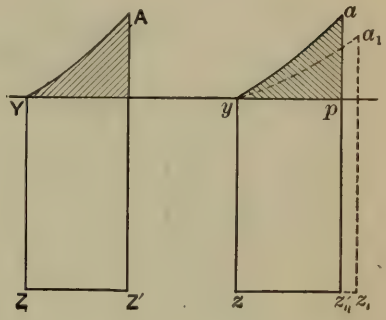


FIG. 75.

(6) Regenerator economizer exchange.

II. NEGATI... $- T_0 (\varphi_2 - \varphi_1) = T_0 (\varphi_1 - \varphi_2)$.

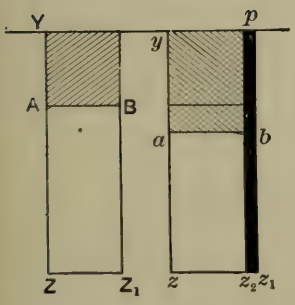


FIG. 76.

Unnecessarily low temperature of refrigerator.

brine

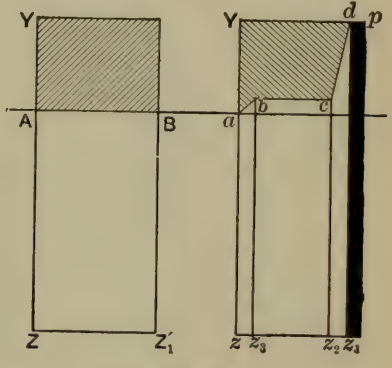


FIG. 79.

Least amount of work to produce a pound of ice—ice engine.

TRANSFER OF HEAT.

I. Positive.—From higher to equal or lower temperature. Dynamic loss = dissipated energy = loss of availability $= T_0 (q_2 - q_1)$.

(*Represented by dark area.*)

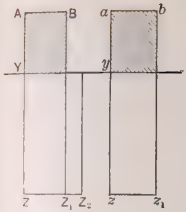


Fig. 70.

(1) Ideal isothermal transfer.

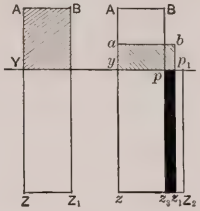


Fig. 71.

(2) Multiple-effect evaporator.

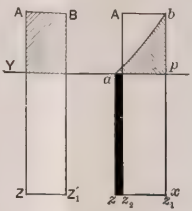


Fig. 72.

(3) Water delivered to boiler.

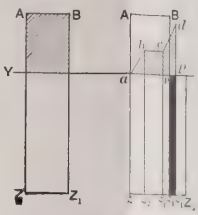


Fig. 74.

(5) Complex.

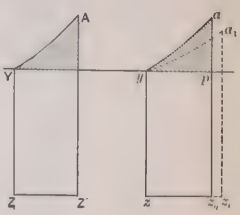


Fig. 75.

(6) Regenerator economizer exchange.

II. Negative.—From lower to higher temperature. Dynamic loss (negative) = increased work $= L = T_0 (q_1 - q_2)$.

(*Represented by dark area.*)

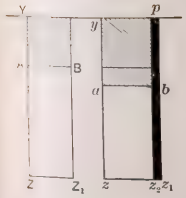


Fig. 76.

Unnecessarily low temperature of refrigerator.

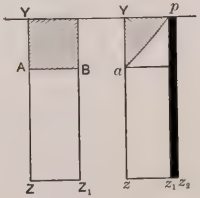


Fig. 77.

Cooling liquid at constant temperature and at falling temperature.

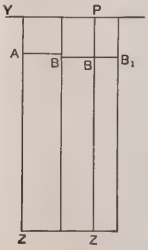
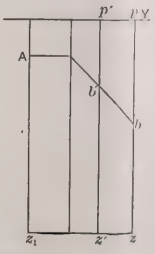


Fig. 78.

Storing "cold" by reducing temperature of brine tank—and at constant temperature.



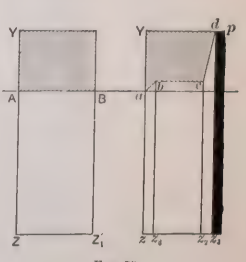


Fig. 79.

Least amount of work to produce a pound of ice—ice engine.

This value of $p z_1$ may be easily shown by construction.

Make the rectangle $yZ_2 = AZ_1 = az_1 =$ heat transferred. Place each of these latter on the former,

then dynamic value $BY =$ rectangle pZ_2
" $by =$ " p_1Z_2
difference $= p z_1$ . . . . . .

Practical examples of this mode of transfer occur in multiple effect evaporators. pz_1 represents the dynamic loss at each stage, or the work which must be done to reverse the process.

In Fig. 72 S remains at the same temperature, but the effect on R of the reception of the heat is to raise its temperature proportionately to the amount of heat received. This is indicated by the rise of temperature along ab. The difference between BY and the triangle abp is obviously the blackened rectangle az_2,

$$\text{for } H = BY + pz_2 = abp + pz_2 + az_2$$
$$\text{and } \quad BY - abp = az_2$$

Hence, in this case also,

$$\text{Loss} = T_0(\varphi_2 - \varphi_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

This case has important practical application, for it occurs whenever an agent is used in a heat engine to effect the transformation. After performing its function, the agent has to be brought from the lower temperature at which it discharged the untransformable heat to the higher temperature, preparatory to taking a new charge of heat. The heat to accomplish this is taken from S at the constant higher temperature with the loss of available energy indicated. A method of obviating this loss will be met with hereafter.

The curve ab, Fig. 73, since it occurs very frequently in questions of heat transfers, demands attention. Its equation may easily be found. Assume R to be of unit mass. An elemental area ms of height T and base $d\varphi$ is expressed as $Td\varphi$. But this same area represents the heat necessary to raise a unit mass through a temperature $np = dt$. If c be the specific heat, then

$$ms = cdt = Td\varphi$$

$$d\varphi = \frac{cdt}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

$$\varphi = c \log_\epsilon T. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

$$\text{or } T = \epsilon^{\frac{\phi}{c}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

and the curve is the logarithmic

$$zz_1 = \varphi_1 - \varphi_2 = c \log_\epsilon \frac{T_2}{T_1}$$

if $T_1 = az$ $T_2 = bz_1$ φ_1 and φ_2 being entropy measured from any convenient starting point. We can usually make this starting point z, so that we have simply

$$\varphi = c \log_\epsilon \frac{T_2}{T_1}.$$

If a tangent be drawn to the curve at any point, its inclination is measured by

$$\frac{pn}{mn} = \frac{dt}{d\varphi} = \frac{T}{c}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

$\frac{d\varphi}{dt}$ occurs more frequently in investigations, and measures the inclination to the T axis

$$\frac{d\varphi}{dt} = \frac{c}{T}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$\text{the subtangent } vZ = T\frac{d\varphi}{dt} = c. \quad . \quad . \quad . \quad . \quad (22)$$

From this latter equation the tangent can be readily drawn at any point. From the foot of the ordinate mv measure off $vZ = c$. Zm is the tan at m. Now, at the temperatures ordinarily used, the logarithmic becomes very nearly a straight line. This may be seen either by drawing a curve or simply by observing the differences of $\log_\epsilon T$, in a table of Napierian logarithms for values above 460, which will be found nearly constant. c is the specific heat when the heat is added under some specified condition. If this condition be equal pressure then $c = C_p$, and the curve is a line of constant pressure or isopiestic. If volume be constant, $c = C_v$ and ab is an isometric.

We may, in most practical applications, avoid drawing the curve. For short distances the tangent through a given point will be nearly identical with the curve, and can be easily drawn as

before mentioned. When the initial and final temperatures are known, the entropy zz_1 may be found with close approximation

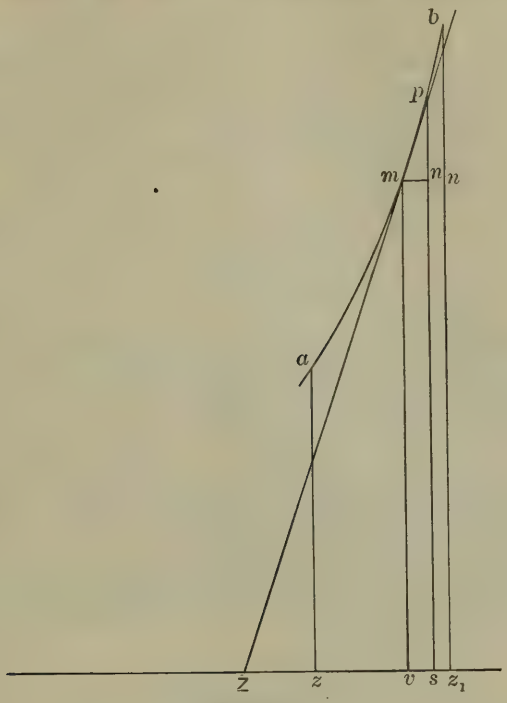


FIG. 73.

if, as is frequently the case, the amount of heat added is also known. If this known heat be q, then

$$zz_1 \frac{(T_1 + T_2)}{2} = q \text{ very nearly.}$$

$$zz_1 = \varphi = \frac{2q}{T_1 + T_2} \quad \ldots\ldots\ldots \quad (23)$$

The area between mv, the isometric curve continued to infinity, and the base line is $C_v T$. The area of the triangle $mvZ = \frac{1}{2} C_v T$. The first area measures the intrinsic energy of the substance at m, and is, therefore, twice the area of the triangle mvZ. If C_v be not constant, then

$$\varphi = \int \frac{cdt}{T} \quad \ldots\ldots\ldots \quad (24)$$

If mass also be not constant

$$\varphi = \int \frac{cmdt}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

In Fig. 74 the source S remains at constant temperature, while R receives the heat under conditions indicated by the combination of curved and straight lines *abcd*. It is easy to see that the loss of available energy in this case also

$$pz_1 = T_0 (\varphi_2 - \varphi_1)$$
$$\text{for } pZ_2 = BY$$
$$p' Z_2 = abcd\ p_1\ a.$$
$$\text{difference} = pz_1.$$

Fig. 75 shows a case in which the withdrawal of heat from S causes a fall in its temperature proportional to the amount of heat abstracted, while the reception of heat by R causes its temperature to rise in proportion to the heat received. In case the curves AY and ay are identical, the triangular-shaded areas are equal, and there is no loss in dynamic value. Here also we notice that the entropy is unchanged.

If the change in temperature of R proceeds along the curve ya_1, then the triangular areas are not equal, and their difference or loss of dynamic value is

$$pz_1 = T_0 (\varphi_2 - \varphi_1).$$

This case is also of great practical interest, as it indicates a second method of transferring heat without loss, and which can be applied and is so applied under the various designations *regenerators*, *heat exchangers*, *economizers*, etc. It should, indeed, be universally used where circumstances permit.

Let S, the body from which heat is to be removed, be of mass m_1 and heat capacity c_1, while the corresponding values for R are m_2 and c_2

$$\left.\begin{aligned} \varphi_1 &= c_1 m_1 \log_\epsilon \frac{T_1}{T_0} \\ \varphi_2 &= c_2 m_2 \log_\epsilon \frac{T_2}{T_0} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

When these are equal there is no loss of dynamic value and the regenerator is perfect. In this case T_1 must equal T_2 (*i. e.*, temperature A = temperature a), or the transfer will not have been complete. We then have as a condition

$$c_1 m_1 = c_2 m_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

which, indeed, is only equivalent to stating that the respective heat capacities of S and R must be equal.

The regenerator is really not a second method of transferring heat without loss of dynamic value, for on examination of its practical details it will be seen that in the perfect regenerator the actual transfers are isothermal. It is then equivalent to Case I., and in practice will fall within Case II. The ordinary feed water heater is not a regenerator The heating by means of flue gases may be so in form as seen from Fig. 72. The assumption being that only so much heat is left in the gases as is necessary for chimney draft, it would seem that this is not a legitimate application of the principle. Moreover, the heat so transferred is not part of that usually included within the cycle. In the absorption process several correct applications of the regenerator occur; the cooling of water by superheating the return gas (in ice making) is correct in principle, but not advantageously applied.

Examples of negative transfer are furnished by Figs. 76 to 79. In all such cases the dynamic value is negative, indicating that work has to be performed. Its magnitude will depend on the temperature at which the transfer is effected, and on the manner of effecting it. In Fig. 76 a unit of heat is represented by AZ_1 and az_1.

The difference in dynamic value or additional work to be performed in the second case is

$$yb - YB = pz_1 = T_0 (\varphi_1 - \varphi_2)^* \quad . \quad . \quad . \quad . \quad (28)$$

$$\text{for } yz_1 = H + yb = H + YB + pz_1$$

$$\therefore yb - YB = pz_1 .$$

This represents the practical loss when refrigeration is effected at a lower temperature than circumstances necessitate.

Fig. 77 shows another common case of misapplication of work. YB is the work necessary to remove a unit of heat *at* the temperature A, the triangle ypa — the work expended if the cooling commences at temperature Y and finishes at temperature a. The loss or excess of work is $pz_2 = T_0 (\varphi_1 - \varphi_2)$.

This loss occurs when water at temperature Y is placed in ice cans immersed in brine at temperature A. The saving would be

* Loss of work $= - T_0 (\varphi_1 - \varphi_2)$ compare with previous cases, loss being now negative indicates that additional work has to be done.

effected by maintaining the temperature of the agent only a few degrees below that of the water, lowering its temperature as that of the water falls.

In a refrigerating plant on the brine system it is frequently sought to store up a reserve by withdrawing heat from a mass of brine. In doing this, the temperature of the brine falls in proportion to the amount of reserve.

In Fig. 78 the right hand shows the dynamic loss by such a proceeding, while the left-hand figure represents a method suggested by the writer of remedying this. A being the normal temperature at which heat is withdrawn from the brine when storage occurs, the temperature falls to b. The work increases at each fall, being proportional to pb, while at the same time the refrigeration is reduced, being proportional to bz, the decreasing efficiency being $\frac{bz}{bp}$.

Apart from the dynamic loss here represented, the capacity of the machine at the same time falls off (for reasons which will be apparent hereafter), so that a point is soon reached at which the reserve ceases to increase. The remedy suggested is to maintain the temperature at A by inserting in the brine tank vessels containing a liquid which will solidify at the temperature A. When this temperature is reached, or a little lower one, BB the work of the machine is expended in removing the latent heat at the constant temperature, and until the operation is complete the efficiency remains equal to $\frac{BZ}{BP}$.

Fig. 79 compares the work expended to produce 1 lb. of ice with that absolutely necessary, the extra work being

$$pz_1 = T_0 (\varphi_1 - \varphi_2).$$

The temperature Aa, at which the removal of heat is effected, is a few degrees below the freezing point of ice. The water is exposed immediately to this temperature, and the work done is represented by the area YB.

Tabulating the heat actually removed:

(1) To cool the liquid to $32 = z_3cdz_1 = c\,(t_1 - 32)$.
(2) To solidify the ice $= z_2cbz_3 = L$.
(3) To cool the ice $= z_2baz = c_1\,(32 - t_2)$.

The work for (1), if the cooling be performed at falling tem-

perature, as in Fig. 77, is represented by that portion of the shaded area between d and the isentropic z_2c produced.

The work for (2) is the rectangular part of the same area, included between the isentropics z_2c and z_3b produced.

In like manner the work for (3) is the area cut off by the last two isentropics produced.

The sum of these or the shaded area is evidently:

$$\left.\begin{aligned} & T_0\varphi_2 - \{ c_1(32 - t_2) + L + c\,(t_1 - 32) \} \\ \text{in which } & \varphi_2 = c_1 \log_\epsilon \frac{T_2}{T_3} + \frac{L}{T_2} + c \log_\epsilon \frac{T_1}{T_2} \end{aligned}\right\} \quad . \quad . \quad (29)$$

T_1 and T_2 being the absolute temperatures, corresponding to t_1 and t_2 and T_3, that of 32° F.

Considering this area as positive instead of negative, it represents the amount of work which could be obtained by the expenditure of a quantity of heat Yz_1 at temperature of surrounding objects, and using the pound of ice as the receptacle for the untransformable heat. The efficiency is a maximum aY at the commencement, decreases along a', remains constant along bc, and finally vanishes when the water of which the ice was composed reaches the temperature Y at d. Such an engine might fitly be termed an ice engine. The store of ice left over from the winter constitutes a means of transforming a portion of the summer heat into work which may receive attention when our supplies of coal are exhausted. From another point of view, it might be termed a periodic engine; its possibility depends on periodic variation of temperature. It is usual to trace our energy back to the sun; to look to it for the heat whence our work is to be derived when we have squandered all our store. It must not be forgotten that the dynamic value of heat is due entirely to the periodic changes of temperature consequent on the revolution of the earth, etc. We gain as much availability by the heat we lose as by the heat we receive.

Available Energy of a System of Bodies.—Closely allied to the question of transfers is a problem of some interest, viz.: the work obtainable from an isolated system of bodies. If 1 lb. of water at 50° be added to 1 lb. of water at 150°, the 2 lbs. soon settle down to a mean temperature of 100°. No heat has disappeared, so that no work has been done. Now, suppose the process to be so conducted as to utilize the available energy,

some of the heat will be transformed, and the final temperature will be less than 100°.

In Fig. 80*a* let *ZA* and *ZB*, *i.e.*, T_1 and T_2, the absolute temperatures corresponding to 50 and 150°. Let the heat passing from *S* be divided into small parts, of which *Az* is the first. The dynamic value of this heat is *Ab*, and the quantity of heat *Bz* has been received by the body *R*. As the process continues, the body *S* falls in temperature, while *R* rises by reason of the reception of the untransformable heat. The action ceases

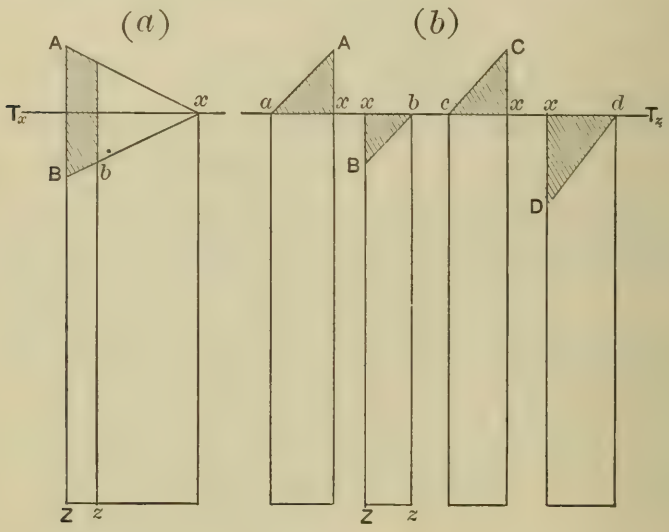


FIG. 80.

when the curves intersect at *x*, which marks the final temperature of the system. The work obtained is evidently the area *AxB*.

The curves *Ax* and *Bx* are known. If *c* be the specific heat of water,

$$\varphi = c \log_\epsilon \frac{T_1}{T_x} = c \log_\epsilon \frac{T_x}{T_2},$$

$$\therefore \frac{T_1}{T_x} = \frac{T_x}{T_2}, \text{ or } T_x = \sqrt{T_1 T_2} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

If *c* be constant, but different for the two bodies,

$$\left(\frac{T_1}{T_x}\right)^{c_1} = \left(\frac{T_x}{T_2}\right)^{c_2}, \text{ or } T_x^{c_1 + c_2} = T_1^{c_1} T_2^{c_2} \quad . \quad . \quad (31)$$

If, instead of taking one pound of each substance, the masses are m_1 and m_2,

$$\left(\frac{T_1}{T_x}\right)^{c_1 m_1} = \left(\frac{T_x}{T_2}\right)^{c_2 m_2}, \text{ or } T_x^{\,c_1 m_1 + c_2 m_2} = T_1^{\,c_1 m_1}\, T_2^{\,c_2 m_2}. \quad (32)$$

The area, $A_x B$, may be calculated to find the available energy, or it may be obtained more simply by remembering that it is equal to the missing heat. If T_m be the mean temperature which the two bodies would have arrived at by simple transfer, this missing heat is evidently (in the case of the water)

$$2\,(T_m - T_x =)\, 2\,(100 - \sqrt{510 \times 610}).$$

We now have at T_x a quantity of matter whose heat capacity is $(c_1 m_1 + c_2 m_2)$. We can combine it with a third body at T_3, whose heat capacity is $c_3 m_3$. The final temperature T_y will evidently be as before.

$$T_y^{\,(c_1 m_1 + c_2 m_2) + c_3 m_3} = T_x^{\,c_1 m_1 + c_2 m_2}\, T_3^{\,c_3 m_3} = T_1^{\,c_1 m_1}\, T_2^{\,c_2 m_2}\, T_3^{\,c_3 m_3}. \quad (33)$$

The process of combination may be continued for any number of bodies, and if T_z be the final temperature of the system,

$$T_z^{\,\Sigma cm} = \Sigma T^{cm} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

A more elegant solution* of this problem, due to Sir W. Thompson, enables us to find T_z by graphical construction. Assuming that such a temperature exists, then all bodies at a higher temperature may be reduced to this temperature by transformation of that portion of their heat represented by its dynamic value. The untransformable heat is discharged into a temporary reservoir at T_z. Thus, in Fig. 80 (*b*) the dynamic values of A and C are represented by the triangles $A\alpha x$, Ccx, the untransformable heat discharged into the reservoir being the rectangles below them. Bodies, such as B and D, of temperature below T_z, are brought up to this temperature by discharging into them the untransformable heat from heat engines de-

* These results are all due to Sir Wm. Thompson. Equation (34) was immediately derived by the simple induction given in the text from a hint in the Encyclopædia Britannica, "Heat," and is inserted as showing the availability of the $T\varphi$ method.

riving their heat from the temporary reservoir. For example, the heat bZ so treated furnishes the work Bbx, and to the body B the heat $ZBbz$ sufficient to raise its temperature to T_z.

When the operation is complete, the temporary reservoir may disappear, since, on the whole, it must have delivered as much heat as it received. (The system of bodies being isolated, no heat can leave it except by transformation.)

Since we are presumed to know c and m, or the heat capacity of each body, we can lay down all the characteristic curves Aa, Bb, etc. Then by trial we can find such an isothermal that

$$\Sigma\varphi = ax + xb + cx + xd + \text{etc.} = 0 \quad . \quad . \quad . \quad (35)$$

(remembering that xb, xd, etc., are negative). This will determine T_z, and the work obtainable is the sum of the shaded triangular areas.

(35) may be written

$$c_1 m_1 \log_\epsilon \frac{T_1}{T_z} + c_2 m_2 \log_\epsilon \frac{T_2}{T_z} + \text{etc.} = 0 \quad . \quad . \quad . \quad (36)$$

which, noting the difference in sign as T is greater or less than T_z, is evidently equivalent to (34).

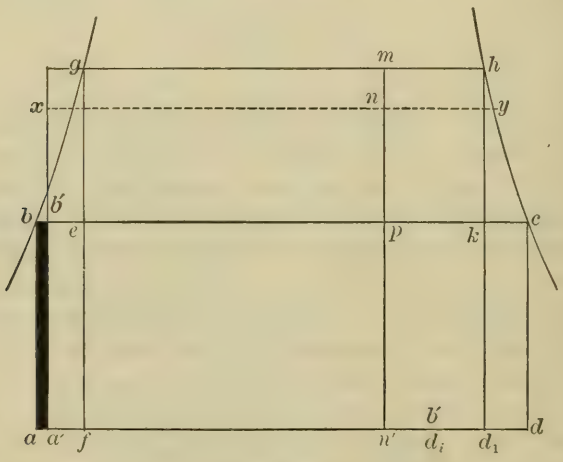


Fig. 81.

The Agent.—It has been already mentioned that the practical operation of either the direct or reverse cycle involves the use of an agent which takes in the heat to be operated upon (at a higher

temperature in the direct, and a lower in the reverse cycle). The transformation being consummated, and the untransformable heat transferred, the agent has to be brought back to the initial temperature. The influence of transfers has been discussed, and we are now in a position to estimate the actual dynamic value of heat treated in any given manner by a series of transfers and transformations. The heat to be operated upon is presumed to exist at constant temperature.

In Fig. 81, let fg represent the temperature (T_2) of the source, and $ab = T_1$, the lowest temperature at which the waste heat can be discharged. Let the agent be a liquid which, by suitable variations of pressure, can be vaporized at the temperatures involved. On the first trip around the cycle let the agent be in a liquid form at b.

By the transfer of heat from the source, the liquid is raised to the temperature g, the heat so applied being

$$abgf = c(T_2 - T_1) \quad . \quad . \quad . \quad . \quad . \quad (37)$$

its dynamic value = bge, and the loss by this transfer is seen at Fig. 72, and also by the dark area, Fig. 81.

The water is now vaporized at T_2, the heat imparted being

$$fghd_1 = L_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (38)$$

and its dynamic value = gk.

The untransformable heat ka is discharged at the temperature T_1, and the agent returns to its starting-point to repeat the course.

The total dynamic value may be most easily found by taking the difference between the heat received by the agent and that discharged, to which it is obviously equal.

$$W = c(T_2 - T_1) + L_2 - ka.$$

$$ka = T_1(be + ek) = T_1\left(c\log_\epsilon \frac{T_2}{T_1} + \frac{L_2}{T_2}\right)$$

$$W = c(T_2 - T_1) + L_2 - T_1\left(c\log_\epsilon \frac{T_2}{T_1} + \frac{L_2}{T_2}\right) \quad . \quad . \quad (39)$$

the ratio of this to the heat supplied, commonly called the efficiency.

$$e = 1 - \frac{T_1\left(c\log_\epsilon \frac{T_2}{T_1} + \frac{L_2}{T_2}\right)}{c(T_2 - T_1) + L_2} \quad . \quad . \quad . \quad . \quad (40)$$

If the absolute dynamic value of the heat as it existed in the source had been obtained,

$$e = 1 - \mu = 1 - \frac{T_2}{T_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

By comparing the values of the last members of Equations (40) and (41) we obtain an idea of the loss per trip for different agents. The same information is arrived at in a simpler manner by reference to the diagram. The dynamic loss is the blackened area bd', which is greater or smaller as the specific heat of the liquid is greater or smaller. This may be compared with the total dynamic value, the size of which depends chiefly on the length gh, which is proportional to the latent heat of the agent. The desiderata, then, in an agent are small specific heat of liquid and high latent heat. By drawing the line xy to rectify the trapezoid of heat supplied, the efficiency (40) may be put in the simpler form (41). If $T_m = nn'$, H = heat supplied, $\Delta\tau = be$, and $x_1 = \frac{bk}{bc}$.

$$T_m\,(x_1\varphi_1 + \Delta\tau) = H$$

$$T_m = \frac{H}{x_1\varphi_1 + \Delta\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

and

$$e = 1 - \frac{T_2}{T_m}.$$

In the same way, other cycles may be reduced to equivalent Carnot cycles, the process being analogous to finding the mean pressure in a pv diagram.

After one trip around of the agent we have a certain amount of work at our disposal. Instead of heating the agent along bg, we may raise its temperature by the use of a portion of this work. If we make the rectangle ga' equal in area to $abqf$, then the work gb_1 so applied, will raise the agent to the temperature T_2. In this arrangement we have abolished the transfer to the liquid, and there is no loss of available energy. The net work delivered in one trip is now gk, which is indeed less than in the previous case, but bears a higher proportion to the heat expended, the ratio being the maximum possible.

Or the saving may be expressed in the fact that a quantity of heat ba_1 which escaped transformation is no longer supplied from the source.

This is the Carnot cycle, devised for eliminating the loss due to transfer. It involves, as we see, both the direct and the reverse cycles; the saving with water-steam as an agent is so small as to preclude its practical application.

There are other transfers involved in the use of an agent, of even greater importance. The vessel in which the agent is contained is subject to the same changes of temperature as the agent. The dynamic effect of the transfers which take place can be ascertained when the amounts and circumstances of transfer are known. These are physical questions of considerable complexity beyond the range of this paper.* Some further attention will be given to them in the subsequent discussion of the practical problems of refrigeration.

The line gh measures the entropy of the latent heat, and h marks the point at which evaporation is completed; further addition of heat would superheat the vapor, and such heat would not be applied at constant temperature.

If the evaporation is not completed, but carried only to m, then steam and water are supplied in the proportions,

$$gm : mh.$$

The heat necessary to evaporate a unit quantity of water at temperature T_1 is bd, of which the entropy is bc. The curve hc is the locus of all points so determined, and an isothermal from gb to hc at any temperature measures the entropy of the latent heat at that temperature.

The curve (called the saturation curve), as drawn for steam, lies to the right of the isentropic hd_1. The agent, therefore, when discharged at T_1, consists of a mixture of steam and water in the proportions,

$$bk : kc.$$

$$\text{Per cent. of steam} = \frac{bk}{bc} = x_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

$$\text{Per cent. of water} = \frac{kc}{bc} = x_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

The isentropics or adiabatics, as hd_1 and gf, being straight lines parallel to the axis of T, their equations are simply the

* See Cotterill, *Steam Engine*, chap. x. Dwelshauvers-Dery, *Étude Calorimétrique de la Machine à Vapeur*, etc.

expression of this fact. Writing φ for the entropy of the latent heat, and τ for the entropy of the heat transferred to the liquid, we have

$$bk - gh = be.$$

For hd_1, $$x_1\varphi_1 - \varphi_2 = \Delta\tau. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (44)$$

For gf_2 $$x_3\varphi_1 \qquad = \Delta\tau. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45)$$

$$\text{where } x_3 = \frac{be}{bc}.$$

For mn, $$x_4\varphi_1 - x_5\varphi_2 = \Delta\tau; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

$$\text{where } x_4 = \frac{be}{bc}, \text{ and } x_5 = \frac{gm}{gh}.$$

Equation 46, which is the most general case, is usually expressed thus :

$$\frac{x_1L_1}{T_1} - \frac{x_2L_2}{T_2} = c\log_\epsilon\frac{T_1}{T_2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (47)$$

or

$$x_1\varphi_1 - x_2\varphi_2 = \Delta\tau. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (48)$$

An adiabatic can be drawn for which the initial proportion of steam and water is the same as the final, by putting $x_1 = x_2 = x$ in (48). Then

$$x = \frac{\Delta\tau}{\varphi_1 - \varphi_2} = \frac{c\log_\epsilon\dfrac{T_2}{T_1}}{\varphi_1 - \varphi_2} = \frac{\Delta\tau}{\Delta\varphi}. \quad . \quad . \quad . \quad . \quad . \quad (49)$$

To preserve this proportion during compression, heat must be added if the adiabatic lies to the left of this one, or removed if it lies to the right. Under these circumstances, we may say that the specific heat of constant steam weight is positive in the first case and negative in the second.

The area $dchd_1$ represents the amount of heat which must have been added to the steam in order that it might have remained saturated during the fall of temperature from T_1 to T_2. kc measures the entropy of this heat, and must evidently be considered negative.

Designating it by ψ, we have

$$kc = -(gh - bc) - be;$$

or $$\Delta\psi = \Delta\varphi + \Delta\tau. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

It being now usual to tabulate the values of φ and τ, the successive values of ψ can also be tabulated. Now $\frac{\Delta T}{\Delta \psi} = \frac{hk}{kc}$ measures the inclination of the curve, so that by tabulating $\Delta\psi$ for each degree of temperature, we can study the course of this curve. It will be found for most agents that $\Delta\psi$ increases (algebraically) passing through the value 0, at which point the adiabatic hd is tangent to the curve. The temperature at which this occurs is the temperature of inversion. For ether, as we shall see, $\Delta\psi$ is positive at ordinary temperature, and decreases for rise of temperature. The specific heat under any given condition being the rate at which heat is transferred as the temperature rises, the specific heat of steam is negative, since, if x is to remain $= 1$, the heat d_1hcd must be *removed*, for a rise of temperature $= kh = dt$. This is also evident from the figure, for the specific heat is the subtangent to the curve hc_1. The graphical significance of the statement that the specific heat of a vapor is negative or positive, is that the curve hc lies to the right of the adiabatic hk in the former case, and to the left in the latter, or that the tangent is negative or positive.

Its numerical value is evidently $T\frac{d\psi}{dt}$ (neglecting sign).

Now, from (50),

$$d\psi = d\varphi + \frac{cdt}{T}.$$

$$\therefore c' = T\frac{d\psi}{dt} = T\frac{d\varphi}{dt} + c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51)$$

$$= T\frac{d}{dt}\left(\frac{L}{T}\right) + c$$

$$= \frac{dL}{dt} - \frac{L}{T} + c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51a)$$

the latter being the usual form under which it is presented. It may be remarked, however, that when the $T\varphi$ ordinates are used there is an obvious advantage in retaining the equations in terms of those variables. The quantity ψ is of sufficient importance in graphical construction to warrant its tabulation, as it

enables us in many cases to pass directly from geometrical measurement to numerical values.

In studying either cycle, the characteristic curves of the agent, viz., *bf* and *hc*, may be drawn, which, in reality, is equivalent to plotting the tabular data. For this purpose tables in either English or metric units may be used, for entropy, being a ratio, is independent of the scale; the fact that all tables are equally available is not the least important advantage of the $T\varphi$ system. The scales for temperature and entropy may be in any proportion. 1 : 100 gives very workable diagrams for steam and ammonia. A convenient plan is to take a drawing board, and arrange on the vertical edges all the temperature scales which are likely to be used. An isothermal can then be drawn at any temperature as given on any scale without the trouble of conversion. This, of course, fixes the scale of temperature; a paper or other scale may be made for entropy, which will be found more convenient than permanent ruling.

If one agent only is to be studied, then its characteristic curves may be drawn. A sufficient length for practical purpose of the isopiestic for superheated vapor may be cut on a triangle from the equation

$$\varphi = C_p \log_e T.$$

In the same manner the isometric curve may be cut to conform to any hypothesis as to the variation of C_v. The lower side of these curve triangles being slid along a T square at T_0 (absolute temperature) isopiestics or isometrics can be drawn through any point.

The solution of any problem then resolves itself into reading off of lengths of lines or computing areas.* This, being simply a question of mensuration, may be done in any convenient order, and the results checked, if desired, by calculation from the corresponding data. As an illustration of the method, a brief study of the refrigeration cycle is given, and the inquiry is conducted with a view to bring out—

(1) The relation between the different cycles in which an agent can be worked. It will be seen that the efficiency $\frac{H}{W}$ is altered, as we pass from the one to the other, by areas added to

* The actual drawing of lines for any particular problem should be done on tracing cloth placed over the board.

H and W respectively. This successive derivation is not, of course, recommended when the object is simply to find the efficiency in any particular case.

(2) The influence which the physical properties of different agents have upon the efficiency of the cycle.

(3) The influence of interchanges of heat between the agent and the cylinder.

(4) The disturbing influence of changes in the normal conditions under which the machine runs.

Ledoux's* classic essay is presumably in the hands of those readers specially interested in refrigeration, which since its revision by three members of this Society has been rendered more available to English readers. The present object being simply the elucidation of the method employed, it was thought that less distraction from it would be secured by closely following the numerical data of the examples there given.

Figs. 82 to 93 give the characteristic curves for ammonia, sulphur dioxide, carbonic acid, and ether respectively, constructed from the tabular data below them. The order of construction is indicated by the order of the letters. In the absence of the complete tables necessary for the accurate construction of the curves hc and gb, they may be represented by straight lines through their initial and final points as found from the data given.

CASE I.—Carnot Cycle. Figs. 82 to 85.

$$H = fk = \varphi_2 T_1 = 138.98$$

$$W = gk = \varphi_2 (T_2 - T_1) = 17.78$$

$$\text{Efficiency} = \frac{H}{W} = \frac{\varphi_2 T_1}{\varphi_2 (T_2 - T_1)} = 7.818 \quad . \quad . \quad . \quad (52)$$

Hence, to find the actual amounts of refrigeration and work involved in the Carnot cycle, we form the fraction,

$$\frac{T_1}{T_2 - T_1},$$

* *Ice-Making Machines*, M. Ledoux, revised and transformed to English units by J. E. Denton, D. S. Jacobus, and A. Riesenberger. (Van Nostrand, 1892.) It is easy to see by what modifications the investigation would apply to the steam engine. On this point, moreover, the reader may consult Cotterill and Hermann, above cited.

CASE I.—CARNOT CYCLE.

$$e = \frac{kf}{gk}.$$

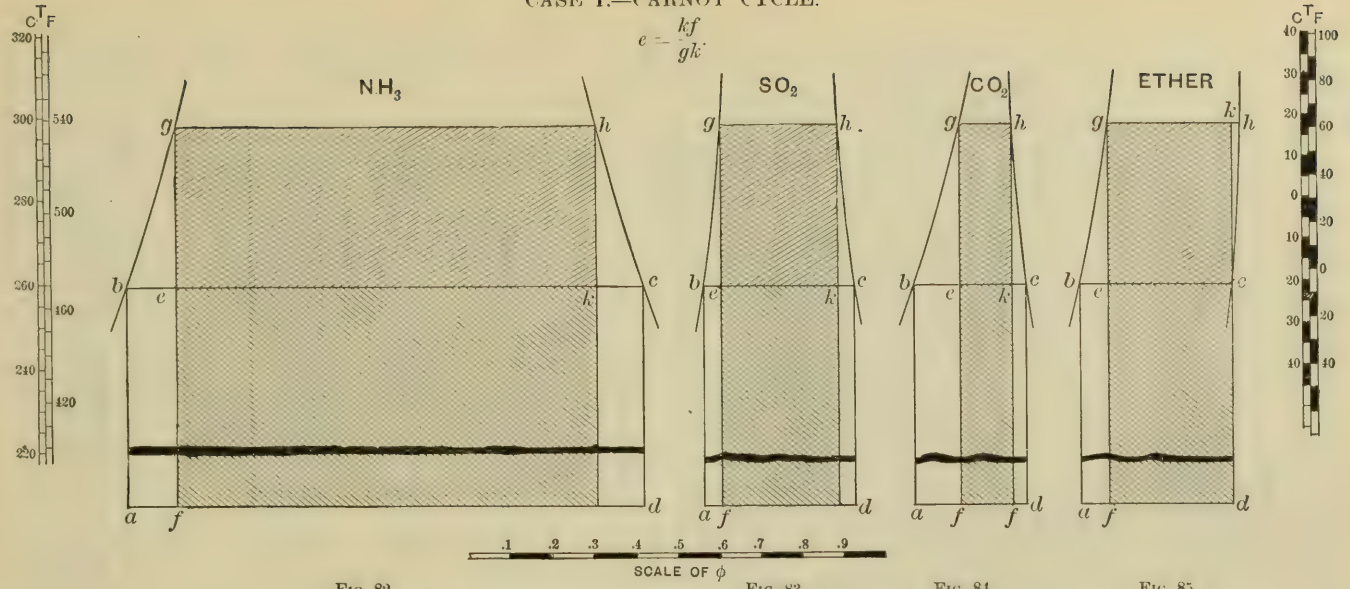


FIG. 82. FIG. 83. FIG. 84. FIG. 85.

TABULAR DATA FOR CONSTRUCTION OF DIAGRAM.—(1 lb. of each.)

	T_1	T_2	L_1	L_2	$\phi_1 = \frac{L_1}{T_1}$	$\phi_2 = \frac{L_2}{T_2}$	$h = \int_{T_1}^{T_2} \frac{cdt}{T}$	$\Delta\tau = \int_{T_1}^{T_2} \frac{cdt}{T}$	$f = \Delta\phi + \Delta\tau$	C_p	$T_3 = T_2 \varepsilon \frac{f}{C_p}$	$b' = C_p(T_3 - T_2)$
Ammonia			580.56	543.03	1.2501	1.0367	60.10	.1216	−.0918	.5084	627.47	
Sulphur Dioxide	464.4	523.8	179.82	156.76	.3678	.2993	21.59	.0437	−.0248	.1544	156.00	
Carbonic acid	t_1 =	t_2 =	121.50	67.93	.2616	.1297	56.72	.1148	−.0171	.2	570.5	
Ether			170.99	165.14	.3682	.3172	31.47	.0698	+.0188	.475		
Represented on diagram by	*ab*	*fg*	rectg. *bd*	rectg. *hf*	*bc*	*gh*	area *abqf*	*be*	*kc*			

and multiply both numerator and denominator by the entropy of the rejected heat for the particular agent used.

If it is desired to know the proportion x of vapor in the mixture as supplied to the cylinder, we have

$$x = \frac{bk}{bc} = \frac{be + gh}{bc} = \frac{\Delta\tau + \varphi_2}{\varphi_1} = 93.242\% \quad . \quad (53)$$

For the proportion of gas at the end of the expansion,

$$x_1 = \frac{be}{bc} = \frac{\Delta\tau}{\varphi_1} = 11.88\% \quad . \quad . \quad . \quad . \quad . \quad (54)$$

The heat supplied H might then have been calculated from these values :

$$H = (x - x_1) L_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (55)$$

which may be used as a verification.

Performing this calculation for the other agents, we obtain,

	NH_3.	SO_2.	CO_2.	Ether.
$H =$	481.21	138.98	60.226	138.58
$W =$	61.581	17.778	7.703	17.725

Efficiency, 7.818 for all.

$R = 1.673$.

The efficiency represents the number of thermal units removed for the work equivalent of one thermal unit, or for 778 ft. lbs. The relationship between the work done and the refrigeration effected is better expressed as the number of tons equivalent refrigeration per day (of 24 hours) effected by one horse-power. If R represent this, then

$$R = \frac{H}{W} \times .214 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

It has no special interest in this case, since the cycle is not used in practice.

The case of ether requires special consideration. This agent (Fig. 85) condenses by compression, the specific heat of ether vapor being positive at the temperatures chosen, as is indicated by the inclination of the saturation curve hc to the left of the isentropic through h.

At the *end* of compression, the proportion of vapor

$$x = \frac{gk}{gh} = \frac{\varphi_1 - \Delta\tau}{\varphi_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

$$H = cf = T_1(\varphi_1 - \Delta\tau);$$

$$W = gc = (T_2 - T_1)(\varphi_1 - \Delta\tau).$$

$$\text{Efficiency} = \frac{T_1}{T_2 - T_1} \times \frac{\varphi_1 - \Delta\tau}{\varphi_1 - \Delta\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad (58)$$

Case II.—Omitting the expansion cylinder. Figs. 87 to 90.

In this case the work to be done is increased and the heat removed is reduced by the same amount; for the work in the expansion cylinder was done at the expense of the heat of the liquid. It now finds its way to the refrigerator, reducing the area of refrigeration by the rectangle *ef'*, which is equal to the additional work area *bge*.

This is evident, since the trapezoid $abgf = h =$ rectangle bf'. If $w =$ area of ef' or gbe, then the efficiency of this cycle is

$$e = \frac{H - w}{W + w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (59)$$

$$w = bf' - bf = h - T_1 \Delta\tau. \quad . \quad . \quad . \quad . \quad . \quad (60)$$

The value for the different agents of w is,

3.612 1.308 3.41 2.072,

respectively, and by performing the operation indicated by Equation (59), we obtain the following values for the different agents:

	NH_3	SO_2	CO_2	Ether.
H	477.60	137.67	56.82	136.51
W	65.19	19.08	11.113	19.8
$\frac{H}{W}$	7.325	7.22	5.11	6.89
R	1.5754	1.5528	1.099	1.482

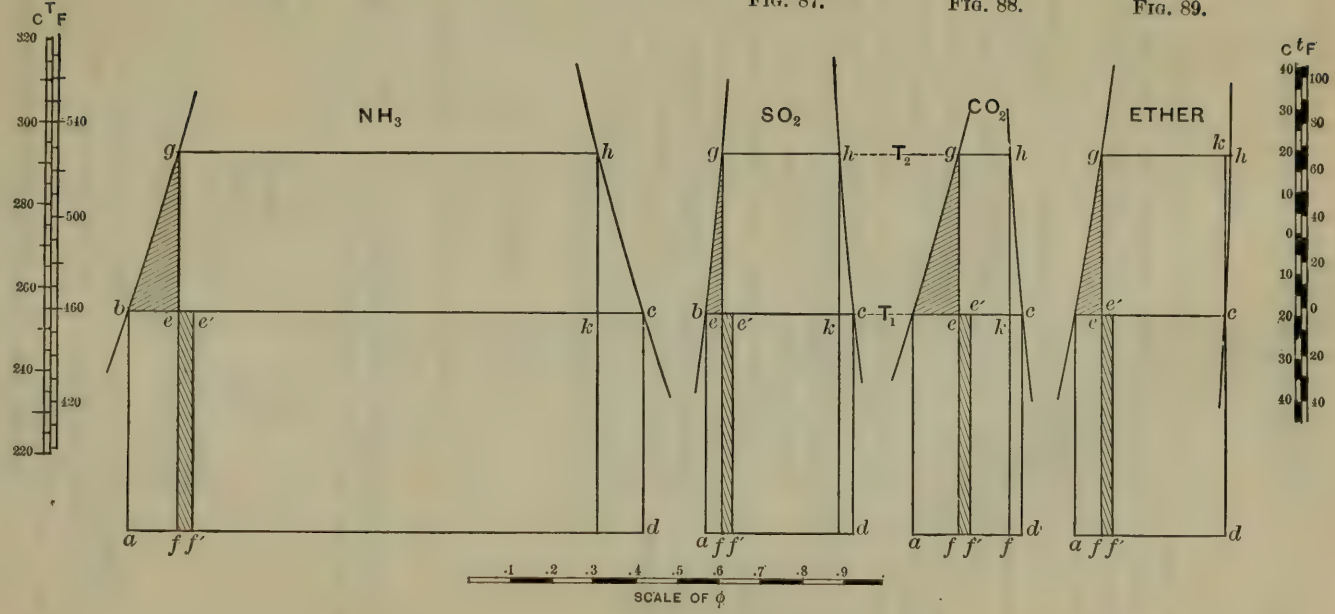
We notice that the inevitable falling off in efficiency by omission of the expansion cylinder is very different in relative amount for the different agents. The per cent. of loss, found by comparing the efficiencies in each case, is, respectively,

6.3 7.2 34.6 11.7,

CASE II.—PRACTICAL CYCLE—WET AGENT.

$$= \frac{kf - ef'}{gk + bge}.$$

FIG. 86. FIG. 87. FIG. 88. FIG. 89.



and the relative value of the agents may be compared by taking ammonia as the standard,

100 98.56 69.76 94.06,

the meaning of which is, that if a given expenditure of work will produce 100 lbs. of ice when ammonia is used, it will produce 98.56 when sulphur dioxide is used, and only 69.76 lbs. when carbonic acid is used.

CASE III.—The agent is furnished to the compressor dry and saturated. Figs. 90 to 93.

In this case the refrigeration is increased (over that of the previous case) by the rectangle kd, and the work to be done is increased by the trapezoid $khjc$. To calculate these areas we must know the temperature dj to which the gas is raised by compression. This may be determined by the consideration that the pressure is unaltered, so that j lies on an isopiestic through h. This isopiestic follows gh as far as h, beyond which it becomes a logarithmic curve, which can be easily drawn, since C_p, the specific heat at constant pressure, is known. In practice it will be sufficiently accurate to draw the tangent through h to this curve. Writing T_3 for the temperature at j,

$$hq = f = C_p \log_\epsilon \frac{T_3}{T_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (61)$$

$$\log_\epsilon T_3 = \log_\epsilon T_2 + \frac{f}{C_p};$$

$$\log_{10} T_3 = \log_{10} T_2 + \frac{f}{C_p \times 2.3062} \quad . \quad . \quad . \quad (62)$$

Substituting the values of f and C_p for each of the agents, we obtain as the final temperatures,

	NH_3	SO_2	CO_2
T_3	627.47	615.35	570.5;
t_3	168	156	111.

Rectangle $kd = T_1 f = w$.

Trapezoid $KHjc = C_p (T_3 - T_2) - T_1 f = w_1$.

Ether, when received in the compressor as a dry saturated vapor, is not superheated by compression. It was considered under the last case.

Any number of other cases might be investigated by draw-

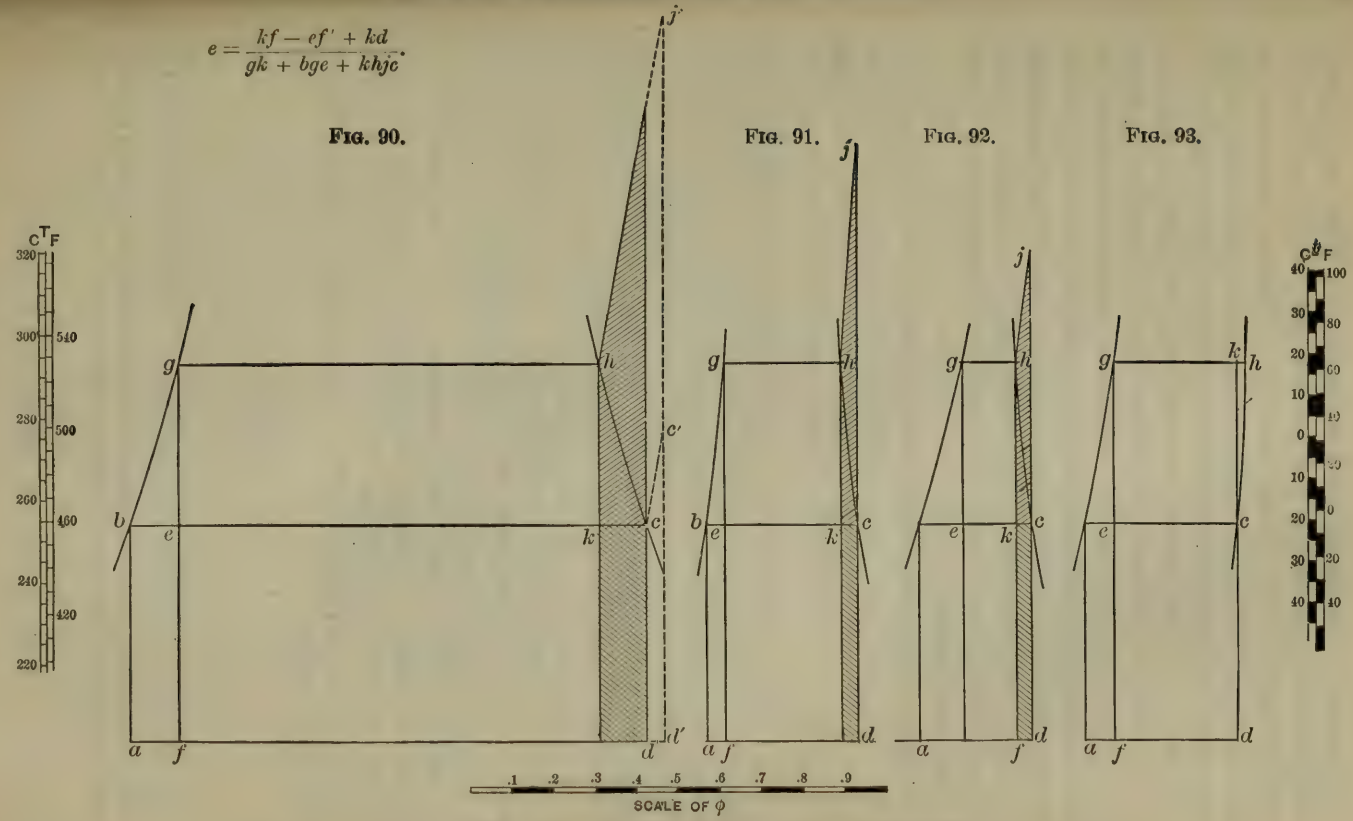
$$e = \frac{kf - ef' + kd}{gk + bge + khjc}.$$

FIG. 90.

FIG. 91.

FIG. 92.

FIG. 93.



CASE IV.—DOTTED LINES, FIG. 90: PRACTICAL CYCLE—SUPERHEATED AGENT.

$$e = \frac{kf - ef + kd + dcc'd'}{gk + bge + khjc + cjj''c'}.$$

ing adiabatics between k and c or beyond c. In the former case the gas will be superheated by compression to a lesser extent, the final temperature being determined by the intersection of the adiabatic with the isopiestic hj. The latter case, which frequently, if not usually, occurs in practice, may be noted.

CASE IV.—Vapor initially superheated. Fig. 90, dotted lines.

The initial superheating will take place along the isopiestic cc_1. If the temperature $c'd'$ is known, c_1 may be determined on the diagram by the intersection of cc_1 with an isothermal distant c_1d_1 from the base line. Producing c_1d_1 to meet the isopiestic through h in j, we observe that additional heat removed (w) is represented by the trapezoid dcc_1d_1, and the additional work (w_1) by the figure $cjj'c_1$.

Writing T_4 for the temperature d_1c_1, and T_5 for d_1j',

$$\left.\begin{aligned} H &= C_p\,(T_4 - T_1);\\ w_1 &= C_p\,(T_5 - T_3) - C_p\,(T_4 - T_1). \end{aligned}\right\} \quad \cdot \cdot \quad (62a)$$

We have to consider how much of this additional heat removed (H) is to be credited to the effective refrigeration. When the brine system is used, only a very moderate degree of superheating can be so credited, since the temperature of the agent in a well-proportioned plant will differ only a few degrees from that of the brine. With direct expansion a much larger proportion may be effective refrigeration, and may be ascertained by observing the temperature of the gas as it leaves the cellars. In all cases, however, a large proportion of this heat is received by the agent either on its way to the compressor or by contact with its walls and passages In a compressor without water jacket or internal cooling the temperature (T_4) may be inferred with tolerable accuracy from the observed temperature T_5 of the discharged gas. For moderate superheating we have very nearly,

$$T_4 = \frac{T_5\,T_1}{T_3}\,^{*} \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (63)$$

If, instead of liquefying the gas in the condenser, we cool it

* If we consider jj' and cc' the tangents to their respective curves, they will both meet in a point, viz., at distance C_p from d ; whence,

$$\frac{T_1}{T_3} = \frac{T_4}{T_5}.$$

only to j (T_3), and then, by adiabatic expansion, cool it to c (T_1), we have the usual cycle for refrigeration with dry gas. This will be considered hereafter; it is noticed here to indicate the natural connection between the two systems. In the meanwhile, it may be noted that there is always a loss in production by running a machine designed for vapor even partially on the permanent gas system.

Before we can estimate the practical efficiency of the compressor, we must consider certain modifications, intentional and incidental, which obtain. Of the former, the most important is cooling during compression, while the action of the sides is an incidental modification not to be neglected.

Cooling during Compression.—Isothermal compression is sometimes spoken of in connection with refrigeration, but it is evident, since T_2 is the temperature of surrounding objects, or the lowest temperature available for cooling purposes, no cooling can be effected in the compressor until this temperature is reached. The route of least possible work is along the adiabatic cq and the isothermal qh, by which the work is reduced by the area of the triangle hjq (Fig. 94). The heat which must be removed to effect this reduction is indicated by the rectangle hd.

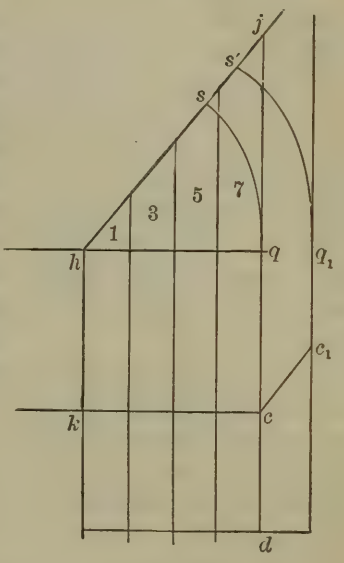


FIG. 94.

$$\triangle hjq = C_p (T_3 - T_2) - T_2 f.$$

$$hd = T_2 f.$$

If we divide this heat area into four parts by equidistant vertical lines, these will also divide the triangle into four parts, the areas being proportional to the numbers 7, 5, 3, and 1 respectively, from which we see the dynamic effect of the first unit removed is 7 times that of the last unit. If there be n divisions, then the first part of the heat removed is $(2n - 1)$ times more effective than the last. Unfortunately, the point at which the removal of heat is most effective is also the point at

which the least heat can be removed, for the difference in temperature between the walls of the cylinder (or any cooling medium) and the agent is a minimum.

The line of compression will leave the adiabatic at q and strike hj as s at some point between h and j, following a curve which is at first very slightly inclined to the adiabatic as qs. But this result is modified, as will be shown.

Action of the Sides.—In considering the mutual interchange of heat between the cylinder and the agent it is important to separate the different periods at which the action takes place, viz. :

(1) During admission.

(2) During compression (thermic stroke).

(3) During expulsion.

The efficiency of a refrigeration machine, it must be remembered, is the ratio of the *effective* refrigeration to the work expended. The heat received by the agent during admission may, since it is received at a temperature above that of the refrigerator, be removed with greater efficiency; but since it represents no part of the effective refrigeration, being, in fact, a bastard refrigeration foisted upon the machine by the action of the walls, the work it occasions is a dead loss. The heat received or rejected during the thermic stroke reveals itself by the modification of the dynamic area; that rejected during expulsion has no immediate dynamic significance. So much of it, however, as is stored in the cylinder walls reappears at a later period.

(1) When the gas first enters the compressor, the walls, passages, and piston, having been heated by the recently discharged gas, are at a temperature higher than that of the agent. The result is that during the filling of the cylinder the agent is receiving heat which cannot be credited to the effective refrigeration, but which has to be removed by the expenditure of work represented by the dynamic value of this heat in the particular cycle used.

For example, in Case II., where a mixture of liquid and gas is supplied in the proportion $x : 1$, this additional heat is represented by the rectangle K_3, Fig. 95, and a portion of the liquid is evaporated so that the proportion of gas at the commencement of compression is

$$x_2 = \frac{bk_3}{bc}.$$

ACTION OF THE CYLINDER WALLS.

Dark area = additional work = dynamic loss. In Fig. 98, *difference* of dark areas = dynamic loss or gain.

An ordinate travelling round the curve of the dark area sweeps out the area representing heat added to and removed from the agent during the thermic stroke.

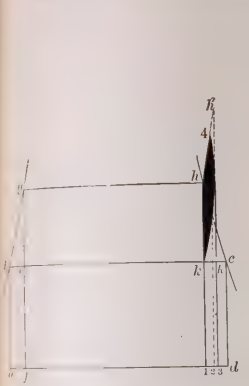


Fig. 95.

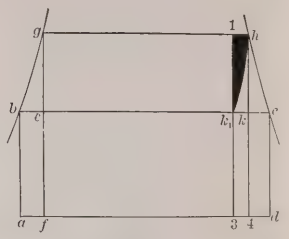


Fig. 96.

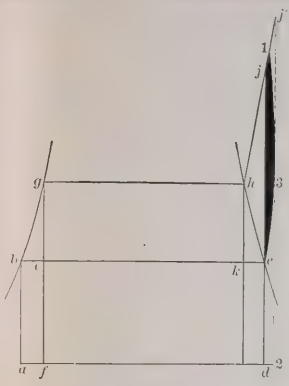


Fig. 97.

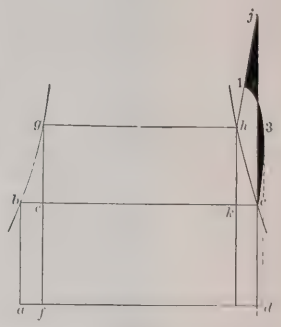


Fig. 98.

Case II.—Wet Compression.

Normal supply of liquid agent.

Additional supply of liquid agent

Case III.—Dry Gas Compression.

Moderate cooling.

Excessive cooling

CHANGE OF NORMAL CONDITIONS OF TEMPERATURE.

Dark area = additional work = difference in Fig. 99; shaded area = loss of refrigeration; cross-section = both; dotted area (Fig. 102) = gain in refrigeration.

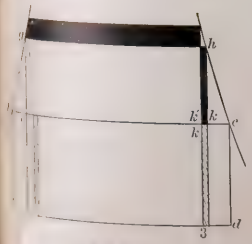


Fig. 99.

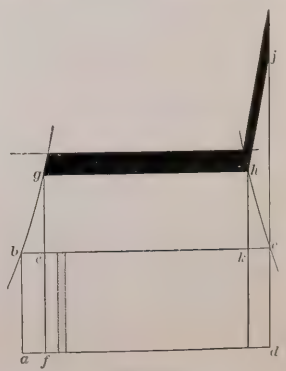


Fig. 100.

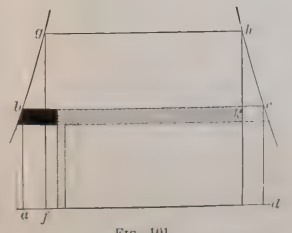


Fig. 101.

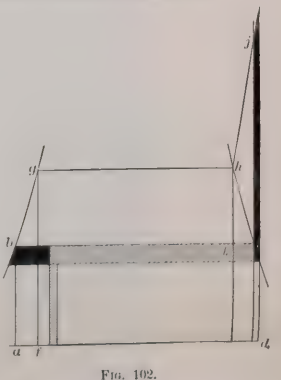


Fig. 102.

Raising the Condenser Temperature.

Case II.—Wet Compression.

Case III.—Dry Gas Compression.

Lowering the Refrigerator Temperature.

Case II.—Wet Compression.

Case III.—Dry Gas Compression.

The adiabatic through k' does not meet the isothermal gh, the gas being superheated to the temperature h', and the work to be done to remove this heat K_3 is given by the area of the trapezoid $khh'k'$. If it is desired to avoid this superheating, then the mixture must contain a proportion of gas less than x when it leaves the refrigerator. Fig. 97, $x = \frac{bk'}{bc}$.

When the gas is delivered from the refrigerator dry and saturated, as in Case III., this action of the sides superheats the gas, and the compression is performed as in Case IV., the result being additional work but no additional refrigeration. The effect of this action of the walls is shown in Figs. 97 and 98.

(2) When compression commences, the walls are still warmer than the agent, and continue so for a portion of the stroke. During this period heat is imparted to the agent, so that its path will be a curved line to the right of the adiabatic. The curvature of this line will be least at the commencement, where the greatest difference in temperature between the agent and the walls exists, and gradually increases till this difference vanishes, after which the line would become an adiabatic but for the fact that, since the walls are henceforth cooler than the agent, the transfer of heat is reversed, the passage now being from the agent to the walls. The curve gs, Fig. 94, previously considered as representing the cooling, must be transferred to the right so as to be a continuation of the curve cc_1q_1, which will now meet the isoprestic in s_1.

The amount of heat involved in this double transfer after the commencement of the thermal stroke is represented by the area swept out by the T ordinate passing around the curve. From T_1 to T_2, where it becomes a tangent to the curve, it sweeps out the area of heat imparted to the agent; thence following the curve till it meets the isopiestic hj, the area measures the heat received by the walls *during* the completion of the compression

The dynamic effect, or increased work, is indicated by the black area. In the wet compressor, so much additional liquid may be brought in with the vapor that the heating during admission and compression will just change the mixture to a dry gas at the end of the stroke. This is the case indicated by Fig. 96. If, however, the quantity of liquid brought in is insufficient for this, the gas will be superheated by compression, as shown in Fig. 95. The dynamic effect with dry compression

is illustrated in Figs. 97 and 98, the former representing the effect with no cooling, or very moderate cooling, such as might come from a water jacket; the latter with a very large amount of cooling, more, probably, than is ever attained.

In Fig. 98 the curve runs out till the temperature T_2 is reached, and instead of thence following the adiabatic $3j$, it bends inwards under the influence of heat abstracted, striking the isopiestic at an intermediate point between j and j'. The action of the walls previous to commencement of the stroke is not shown; its effect if the gas were saturated initially would be to superheat it before compression, converting Case III. into Case IV. From this we see how little is to be learned from the final temperature of the gas when we know only its state before *entering* the cylinder.

Fig. 98, representing excessive cooling during compression, is sufficiently clear. The dynamic gain by cooling is the *difference* of the areas right and left of the adiabatic dj. It is easily seen that in order that these may be merely equal, a considerable amount of cooling must be done; and then only the area of work is the same as it would have been along the adiabatic. On the indicator diagram the effect of this double transfer should be seen by a rise during the first period above the true adiabatic, followed by a fall, the curve crossing the adiabatic if sufficient heat is withdrawn from the agent. When we consider that the time during which each of these transfers can take place is only a fraction of the period of one revolution, we may easily conclude that *dynamic* significance is very small.

(3) The quantity of heat removed by the water jacket has little or no bearing on this question. The heat transferred to the cylinder walls during the subsequent period of expulsion plays the most important part. Part of this passes through the walls into the jacket, and part remains stored up. The former is rejected from the system, and in receiving it the jacket is merely a continuation of the condenser. The amount of heat stored up in a given particle of iron depends on its nearness to the inner surface and the length of time it has been exposed to the difference of temperature.

All this stored-up heat must be imparted to the agent; causing the superheating during inflow and initial compression already considered, so that each particle of iron returns to its original temperature. Thus the heat received by each particle is expressible as periodic function, and the total heat

stored up is a combination of these. Evidently the most important factors are the periodic time and the range of temperature. We may say that the greater the speed the less heat stored up, and the greater the range of temperature the more stored up; that a jacket may diminish the amount by tending to preserve a lower average temperature in the metal, and that this effect should be more marked the slower the compressor is run. When a steady speed is preserved for some time, there is a constant flow through the cylinder walls, and a constant amount stored and restored.*

The process of drawing water from a well with a leaking bucket may serve to roughly illustrate the principles herein involved. One hundred pounds raised ten feet represent 1,000 foot lbs. of work expended, but if 10 lbs. leak out from the bucket on its way, more than 900 foot lbs. of work will have been expended in furnishing the 90 lbs. of water remaining. The dynamic loss depends on the *amount* leaking, and also at the *period of the stroke* at which it occurred, being small per unit of leakage at the commencement of the stroke, and a maximum at the end of the periodic time when the most work has been (uselessly) done on the leaking water. It is easily seen that this loss will decrease by diminishing the periodic time, *i.e.*, by drawing faster, for in that case sufficient time will not have elapsed for the leakage of 10 lbs. of water.

Internal cooling stands on a different footing. Its greatest influence is to be sought, not, as is generally supposed, on the work diagram, but in the modification it effects on this mutual transfer. It acts on those particles of iron most actively engaged, and by decreasing the range of temperature to which they are exposed, neutralizes to that extent the pernicious effect of this double transfer, as seen in Fig. 98. The effect of this mutual action is to reduce the efficiency of the cycle, since additional work has to be done without any equivalent effective refrigeration. It is still more marked in reducing the productiveness of a given compressor, for the density of the gas being reduced by the superheating, a less weight of the agent is passed

* Further consideration of this important question would carry us beyond the limits of this article. Sufficient has been done, it is thought, to show the adaptability of the $T\varphi$ diagram to such questions. See Cotterill, above cited; also Denton, "Performance of a Seventy-five-ton Refrigerating Machine," *Transactions American Society Mechanical Engineers*, vol. xii.

through at each stroke. It would seem that, in the absence of internal cooling, the maximum product would be obtained by allowing the gas to reach the compressor with such a proportion of liquid that at the commencement of the stroke it would be in a dry saturated condition.

Radiated Heat.—In an unjacketed cylinder there is a loss or gain of heat according to the cycle used. All heat received represents a loss of efficiency, the loss being greater or less the earlier or later it is received in the thermal stroke. All heat rejected represents a corresponding gain in efficiency.

With wet compression, Case II., heat is received through the compressor walls during the whole thermic stroke (for the compressor is always cooler than surrounding objects), and in greatest quantities where its influence per unit is greatest; namely, at the commencement of the stroke. In view of these circumstances, it is somewhat singular that wet compressor cylinders are never clothed. Indeed, this case is strictly the inverse of the steam cylinder in the heat engine, and it is an open question whether an economy might not be attained by jacketing with the agent. Thus the agent-jacket controversy may be transferred to the refrigeration cycle, not even the film of moisture being wanting. In the case of dry compression, heat is received through the walls during the earlier part of the thermic strike (if single-acting), and rejected during the latter part. As the greater part of the cylinder is always warmer than surrounding objects, more heat on the whole is rejected than received. The dynamic significance of this heat has already been considered. Omitting all such heat as is rejected after the completion of the thermic stroke, that rejected during the second part of this stroke is probably not much greater than that received during the first part, and its dynamic value is much less, so that, on the whole, there is a loss of efficiency, though not so great as in the case of the wet system.

Figs. 99 to 102 explain themselves, indicating how the loss or gain consequent on a change of the normal conditions of running can be represented by simply drawing on a diagram the isothermals corresponding to the new conditions.

In discussing the various agents, a unit weight of each has been taken. It is interesting to note the relative volume handled per unit of refrigeration, since this determines the size of the compressor to produce a given result with each agent.

The work actually performed is, of course, in all cases greater than the value of W just found. The losses by friction, etc., for a given expenditure of work, bear some not very easily defined relation to the displacement. Diminished displacement implies increased mean pressure and the mechanical difficulties of contending with it; but we may assume that smallness of specific volume is a quality to be desired in an agent.

If u be the specific volume of the agent, then in Case II. (Case I. not being considered, because not used), $\frac{xu}{H}$ = volume of agent per unit of heat removed.

NH_3.		SO_2.		CO_2.		Ether.
16		44		4		223
4	:	11	:	1	:	56

We see that carbonic acid has the advantage in point of volume. In view of the enormous loss consequent upon the suppression of the expansion cylinder, it has ample need of this to justify its use as a refrigerating agent.

With regard to the different cycles discussed, the complete or Carnot cycle can hardly be said to be in practical use in connection with a liquefiable gas. Expansion cylinders have in isolated cases been applied to ammonia, but the gain to be obtained with moderate range of temperature is too small to warrant such a complication. The modern reviver * of CO_2 as an agent proposes to use the complete cycle, but whether it has been brought to a practical issue is not known. Others † have sought to partially recover by indirect means the availability dissipated by the uncompensated transfer of the warm liquid.

It is evident from the diagram that the loss of effect on this account increases with the range of temperature. In practice, the liquid is rarely reduced to the lowest available temperature before injection, and an economy might be effected by the employment of a device analogous to the feed-water heater in the steam engine.

The mixture of vapor and liquid required in Case II. may be effected in either of two ways:

(1) The amount of liquid injected into the refrigerator may be

* U. S. patent 460,696. F. Windhausen.

† U. S. patent 415,881. R. Pictet. U. S. patent 464,348. P. Beck.

so regulated with respect to the surface that the proper proportion of liquid may be carried over unevaporated. This is analogous to *priming* of the boiler.

(2) The agent may be completely vaporized, and the required liquid added at or near the compressor.*

The former method is in general use, more particularly in Europe, although the second admits of closer regulation, and is independent of the proportions or position of the refrigerator, a matter of some importance when direct expansion is used.

The third cycle, in which the gas enters the compressor dry and saturated, is usually employed in this country. When ether is used, the only practicable cycle may be considered as being either the second or third. In practice, the third cycle usually passes into the fourth.

Failure of all the Cycles.—If the temperature at which the heat is rejected be raised, we notice that the adiabatics through e and k, which determine the amount of heat removed, approach each other, and if the isopiestic bg (Fig. 81), ever intersects the saturation curve, this area would vanish. When this happens,

$$ek = \varphi_1 - \Delta\tau - f = 0.$$

The mechanical explanation of this result is that the work done by the agent in the expansion cylinder is just equal to that done on the agent in the compressor. The agent leaves the expansion cylinder in the form of a mixture of such proportions that the compressor will restore it to the liquid condition.

In the second cycle the refrigeration ceases at an earlier period. That is, when (Fig. 86)

$$e'k = 0,$$

or

$$\int_{T_1}^{T_2} c\,dt - fT_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (64)$$

by tabulating the values of the two members of this equation, we can find the value of T_2 for which it vanishes.

---

* The second method was patented by the writer in 1882. The first method was introduced by Linde two years earlier.

In the third cycle (Fig. 90) the failure is delayed until $e'c = 0$, or

$$L_1 - \int_{T_1}^{T_2} c\,dt = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (65)$$

This question, however, has little practical interest further than indicating the adaptability of the various agents for different conditions. We see from the figures that NH_3 and SO_2 can be worked, if desired, with advantage in the second cycle, but that CO_2 is liable to become ineffective unless worked in the third or fourth cycle. With regard to this limiting temperature, it may be remarked that we are not justified in using the empirical formulæ for L, c, etc., beyond the temperatures for which they were determined.

The latent heat we have considered consists partly of external work and partly of internal work. If we divide each entropy line joining the isopiestic and the saturation curves in the proportion of these two, we get a third line, the horizontal distance of which from the saturation curve measures the entropy of the heat equivalent of the outer work.

The intersection of this third curve with the isopiestic determines the critical temperature of the agent. The latent heat at this point is all applied to external work, and the agent hereafter is a permanent gas. With CO_2 it appears that the external work vanishes with the internal, so that the critical temperature marks the limit of refrigeration in the Carnot cycle, which limit must be reached earlier in Case II. When, therefore, a high temperature obtains in the condenser, this agent may be considered to be on the border line between the permanent-gas and liquefiable-gas systems, and to partake of both. It is not easy to see wherein it is superior to air of great density. The inference seems to be that its proper place is lower down on the scale of temperature, as an auxiliary for producing extremely low temperatures.

The foregoing methods seem well adapted to facilitate the study of the characteristics of the various agents and the relations of the different cycles. When discussing the various conditions under which a given machine may work, a somewhat different course may be pursued with advantage. Since the agent in this case is determined on, and also the cycle, the most suitable unit is the volume of the compressor. If we represent by curves the amount of refrigeration, and the work done by

passing a cubic foot of the agent through the compressor, we obtain what may be termed the characteristic curves of the machine. An example of such curves is given in Fig. 106.

The unit is a cubic foot of the agent—in this case ammonia—the supposition being that it is utilized according to the third cycle; that is, the ammonia reaches the compressor in a dry saturated condition.

The base line consists of a scale of temperature, the corresponding gauge pressure being marked below for convenience. The curves start from temperature of the condenser, in this case 80°. An ordinate, as AB, represents on some convenient scale the amount of refrigeration, R, obtained by using a cubic foot of gas between the temperatures 80° and that through which AB is drawn. This value of R is the area $ef'dc$ in Figs. 86 and 90.

$$R = \left(L_1 - \int_{T_1}^{T_2} c dt\right)\delta \quad . \quad . \quad . \quad . \quad . \quad . \quad (66)$$

where δ is the density at T_1, the curve having been traced by plotting a series of values of R. In like manner the values of the area *bcjhg*, Fig. 90, the work done to produce the refrigeration R under the given conditions. An ordinate, as BC, represents in some suitable units the work done to produce the refrigeration BA. The units were so chosen that the efficiency

$$\frac{R}{W} = \frac{AB}{BC}$$

expresses the amount of refrigeration in tons per day per horse-power. The reciprocal $\frac{BC}{AB}$ will therefore represent the amount of refrigeration (in tons per day) for the expenditure of one horse-power. The cost per ton is directly proportional to this latter ratio, which is plotted as the curve marked cost per ton for fuel.

From these curves* we can study the variation in efficiency for a compressor of fixed volume, as the temperature of the refrigerator is changed. The variation of AB represents the change in actual production; the variation of BC that of the

* Lack of time having prevented the construction of a more complete diagram, Fig. 106 is reproduced from "Ice and Refrigeration," March, 1892, where a fuller discussion of practical problems on these lines will be found.

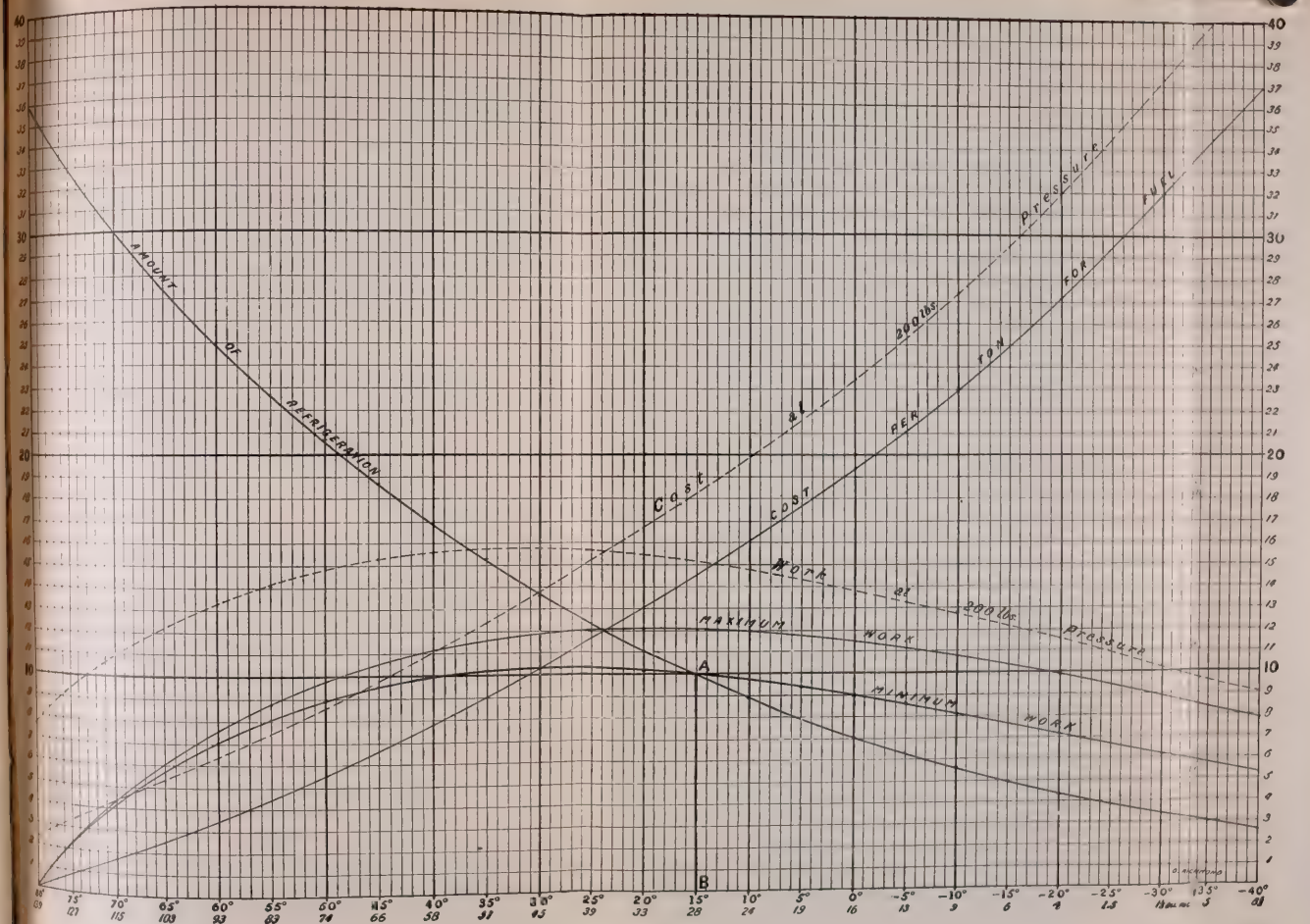


Fig. 106.

Characteristic Curves of Machine

power used; while the corresponding variation of cost is measured by that of *BD*. We see that as the temperature of the refrigerator falls, the absolute useful effect falls; so, also, does the work performed, but at a smaller rate, the efficiency being inversely as the ordinate *BD*.

By the aid of these characteristic curves, after making such allowances as practice calls for, such as action of walls, clearance, friction, etc., solutions to nearly all the practical problems relating to the performance of a machine can be read off with tolerable accuracy when the volume swept out per minute by the compressor is known. In the diagram as actually drawn, if

V = volume per minute of compressed gas;

h = pounds coal per horse-power;

m = cost of coal in dollars per ton;

R, W, K = ordinates to the refrigeration work and cost curves, respectively, then,

For comparative results at different temperatures of refrigerator, represented by the subscripts $_1$ and $_2$,

Capacity of machine	$= R_1 : R_2$;
Work to run it	$= W_1 : W_2$;
Cost for fuel	$= K_1 : K_2$;
Tons refrigeration per horse-power	$= \left(\frac{R_1}{W_1}\right) : \left(\frac{R_2}{W_2}\right)$;
Horse-power per ton of refrigeration	$= \left(\frac{W_1}{R_1}\right) : \left(\frac{W_2}{R_2}\right)$.

For positive numerical results:

Capacity in tons per 24 hours	$= .0283\ VR.$
Work required (in horse-power)	$= .0283\ VW.$
Cost for fuel in mils. per ton	$= mhK.$
Tons per horse-power	$= \frac{R}{W}.$
Horse-power per ton	$= \frac{W}{R}.$
Tons refrigeration per ton of coal	$= \frac{.83}{h}\left(\frac{R}{W}\right).$

PERMANENT GAS AS AN AGENT (AIR MACHINE).

It has been already noticed that when a liquefiable gas is considerably superheated, the cycle partakes of the character of what is known as that of the air machine. The one may be consid-

ered an extension of the other, and will be briefly considered, the interest in it being almost entirely limited to the thermodynamic principles involved, since, except in particular applications, it has gone out of use.

The heat is supplied by the refrigerator at constant pressure along the isopiestic cc_1, Fig. 104. By compression, the tempera-

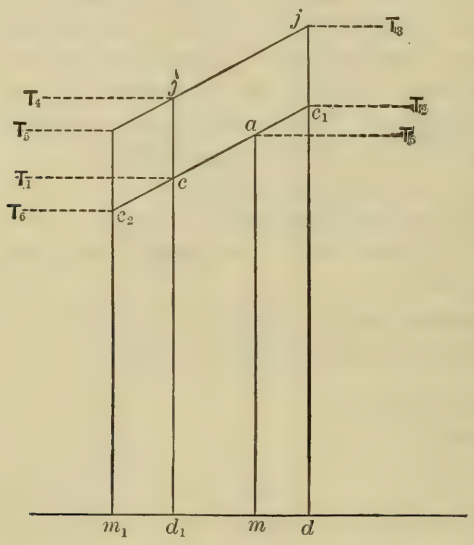


FIG. 104.

ture is raised to j_1. Heat is rejected into the condenser along the isopiestic jj_1, and, finally, the temperature is reduced to c in the expansion cylinder. The cycle therefore has the general characteristics of Case I.

The heat removed is represented by the figure $dcc_1d_1 = H$; the work done, by $cjj_1c_1 = W$.

$$* H = C_p (T_2 - T_1);$$
$$W = C_p (T_3 - T_4) - C_p (T_2 - T_1).$$

$$\text{Efficiency} = \frac{(T_2 - T_1)}{(T_3 - T_4) - (T_2 - T_1)} \quad . \quad . \quad . \quad (67)$$

If the cycle be reversible, $\log_\epsilon \frac{T_2}{T_1} = \log_\epsilon \frac{T_3}{T_4}$, and $\therefore$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

* Compare Equations 62(*a*) supra.

Dividing numerator and denominator of (67) by $T_2 - T_1$, we obtain,

$$\text{Efficiency} = \frac{1}{\frac{T_3 - T_4}{T_2 - T_1} - 1} \quad . \quad . \quad . \quad . \quad (69)$$

From (68),

$$\frac{T_2 - T_1}{T_1} = \frac{T_3 - T_4}{T_4}$$

or,

$$\frac{T_3 - T_4}{T_2 - T_1} = \frac{T_4}{T_1}.$$

$$\text{Efficiency} = \frac{1}{\frac{T_4}{T_1} - 1} = \frac{T_1}{T_4 - T_1} = \frac{T_2}{T_3 - T_2} \text{ by (68)} \quad . \quad (70)$$

The heat cannot usually be taken from the refrigerator at a temperature rising to the temperature T_2, at which compression begins. This is, therefore, a case in which a regenerator may be applied with advantage. If we assume $T_2 = T_4$, temperature of surrounding objects, and $T_5 = mn$, the highest temperature available for refrigeration, then there would be a loss of refrigeration $= mac_1d_1$. By means of a regenerator this heat may be utilized to continue the cooling after leaving the condenser at temperature T_4. This action is indicated by simply moving the heat area over to the left. The temperature of the gas on entering the expansion cylinder is now T_5, and the final temperature T_6. The additional refrigeration $m_1c_2cd_1$ is obtained.

The $T\varphi$ diagram lends itself to the representation of the mutual relation of C_p, C_v, R, and γ.

In Fig. 105, draw an isometric Ov and an isopiestic Op through O to meet the isothermal through T_4. Then

$$\varepsilon^{\frac{av}{C}} = \varepsilon^{\frac{ap}{C_p}}, \text{ or } \frac{C_p}{C_v} = \frac{ap}{av} = \gamma. \quad \frac{vp}{av} = \gamma - 1.$$

Also,

$$ZOpZ_2 = ZOvZ_1 + (vZ_2 - Ovp);$$

that is,

$$C_p(T_2 - T_1) = C_v(T_2 - T_1) + R(T_2 - T_1),$$

for vZ_2 = area included between vp and the isometrics through v and p to infinity.

$\therefore Vz_2 - Ovp$ = area between Op and the same isometrics = $p(v_2 - v_1) = R(T_2 - T_1)$ since $pv = RT$.

Therefore,

$$C_p = C_v + R, \text{ and } C_v = \frac{R}{\gamma - 1};$$

that is, for a perfect gas, heat added along an isopiestic = increase in intrinsic energy + outer work.

If ov_1 be the isometric of a vapor, and ov the isometric it would have when a perfect gas, then the heat added along ov_1

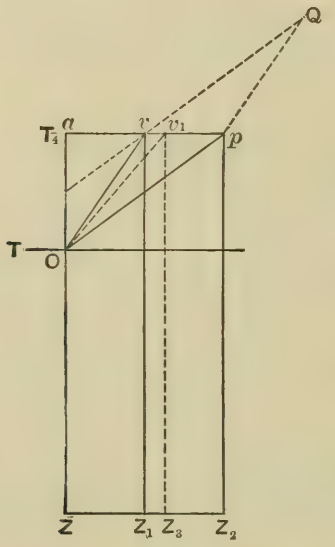


FIG. 105.

may be considered as consisting of two parts, that along ov being applied to heating the substance, that along vv_1 being latent heat of molecular work. If C_p is regarded as constant, then the variation of outer work will evidently indicate the deviation of the substance from the state of permanent gas.

Those familiar with the pv method of presenting these relations (Equations 67), will miss the classification of work there used; namely, for the compressor, the work of compression and the work of expulsion, and the same pair in the expansion cylinder. These, however, may be identified if desired.

W of Equation 67 may be written

$$W = C_p(T_3 - T_2) - C_p(T_4 - T_1)$$
$$= C_v(T_3 - T_2) - C_v(T_4 - T_1) + R(T_3 - T_2) - R(T_4 - T_1)$$
$$= \frac{p_3v_3 - p_2v_2}{\gamma - 1} - \frac{p_4v_4 - p_1v_1}{\gamma - 1}$$
$$+ (p_3v_3 - p_2v_2) - (p_4v_4 - p_1v_1) \quad . \quad (71)$$

When superheating occurs with the use of a liquefiable gas, we found the final temperature of the compressed gas in terms of the tabular data without further calculation. Equation (61) may be written,

$$\frac{T_3}{T_2} = \varepsilon^{\frac{C_p}{f}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

f can be taken from the tables when the adiabatic passes through the point C. For any other position, f may be identified as the entropy of the heat necessary to carry the body from the starting-point of compression along the saturation curve to h, or simply the difference in entropy between h and that point, which can always be found when sufficient data are given to identify the starting-point. The numerical results should agree with those of Ledoux, since he also assumes C_p to be constant, and no other quantity which might be in dispute is involved. The formula in determining T in terms of p given by him may sometimes be more convenient, and the method adopted of deducing this from the Zeuner equation for superheated gas,

$$PV = BT - CP^n. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (73)$$

as an instructive example of the picturesque results of exclusive devotion to the pv ordinates.

The final result,*

$$\left(\frac{T_3}{T_1}\right)^{\frac{C_p}{B}} = \frac{p_3}{p_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (74)$$

is reached through several pages of analytical work of so complex a nature that the revisers have added another page of symbols in explanation.

By using the $T\varphi$ notation for an adiabatic, we have

$$d\varphi = \left(\frac{d\varphi}{dt}\right)_p dt + \left(\frac{d\varphi}{dp}\right)_t dp = 0. \quad . \quad . \quad . \quad (75)$$

* Ledoux, pp. 105 to 110.

Now $$\left(\frac{d\varphi}{dt}\right)_p = \frac{C_p}{t}; \quad \ldots \quad \text{from (21)}$$

and $$\left(\frac{d\varphi}{dp}\right)_t = -\left(\frac{dv}{dt}\right)_p = -\frac{B}{p} \text{ from (73);}$$

$$\therefore C_p \frac{dt}{t} - \frac{B dp}{p} = 0.$$

$$T^{C_p} P^{-B} = \text{constant} \quad \ldots \quad (76)$$

which is equivalent to (74).

For any other than adiabatic, the relation between $TP\varphi$ is evidently

$$\varepsilon^{\phi} = T^{C_p} P^{-B} \quad \ldots \quad (77)$$

For a perfect gas, in the same manner, taking

$$d\varphi = f'(pv) = 0,$$

we obtain

$$\varepsilon^{\phi} = P^{C_v} V^{C_p}, \quad \ldots \quad (78)$$

or,

$$\varepsilon^{\frac{\phi}{C_v}} = P V^{\gamma} \quad \ldots \quad (79)$$

If φ is constant, the equation to the adiabatic in terms of pv is

$$P V^{\gamma} = \text{constant} \quad \ldots \quad (80)$$

We cannot apply this to obtain the adiabatic of a gas near the point of liquefaction, since C_v is not constant.

If we are resolved to find the adiabatic in terms of p and v, then we must eliminate T between the original and derived equation. The only reason for so doing appears to be the expressing of the work of compression and discharge in terms of the pv ordinates, and it would seem that any results so arrived at can be reached by much less laborious means directly from the $T\varphi$ diagram.

Certain thermodynamic relations have been used without proof, viz :

$$\left(\frac{dp}{dt}\right)_v = \left(\frac{d\varphi}{dv}\right)_t, \text{ etc.}^*$$

* *Theory of Heat*, J. Clerk Maxwell. chap. ix., also De Volson Wood. *Trans.* A. S. M. E., vol. xi. p. 1007.

These can be proved as easily from the $T\varphi$ diagram as from that of the pv coördinates, representing a simple geometrical fact which may be thus stated.

If one corner of a parallelogram passes through the intersection of a pair of rectangular coördinates, then the area of such parallelogram is equal to four rectangles formed by taking in pairs segments of the coördinates. These segments may be easily identified. In Fig. 105 complete the parallelogram $OpQv$. Name the two sides op, ov, passing through O, p, and v respectively, and the sides opposite to them, p' and v', respectively.

A product of segments, then, is thus defined:

The projection of p on one axis $\times$ distance along other axis to p'.

There are evidently four such pairs, and their analytical significance is apparent if we suppose p and p_1 consecutive isopiestics δv apart, and vv' consecutive isometrics δp apart. The area $\delta p \delta v$ may, by our convention as to units, be considered either a unit of work or heat. The rectangles in question then each = 1. Having satisfied ourselves as to the geometry of the question, it is not even necessary to draw the figure, for obviously the projection of p on φ measures the increase of entropy while the body passes from one isometric to the next, along a path of equal pressure; *i.e.*, the rate is expressed by $\left(\frac{d\varphi}{dv}\right)_p$. In the same manner, the length along T to meet p' measures the increase in temperature for the passage from one isopiestic to the next along a path of constant entropy; that is, $\left(\frac{dt}{dp}\right)_\phi$;

or,

$$\left(\frac{d\varphi}{dv}\right)_p \left(\frac{dt}{dp}\right)_\phi = 1; \text{ or, } \left(\frac{dt}{dp}\right)_\phi = \left(\frac{dv}{d\varphi}\right)_p \quad . \quad . \quad . \quad (81)$$

and so on for the others. For a required substitution it is only necessary to identify the line representing the given partial differential. The complementary segment on the other axis can be written down at once. A convenient aid to the memory is obtained by writing the variables thus:

$$\frac{p}{t}\Big|\frac{\varphi}{v}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (82)$$

from which a number of frequently recurring equalities can be

written down with certainty. For example, the partial differential representing the relations in question are thus identified:

$$\frac{p}{t}\Big|_v = \frac{\varphi}{v}\Big|_t,$$

$$\frac{p}{\varphi}\Big|_v = -\frac{t}{p}\Big|_\varphi, \text{ etc.}$$

Any of the differentials is considered a sequence of three letters; its equivalent is a reverse sequence commencing with the fourth letter.

As to sign, it is positive if the first pair of letters form a vertical row; it is negative if they form a horizontal row, the n in horizontal furnishing the clue.

Since the reciprocals of these are true, this furnishes us with eight equalities.

Also,

$$\frac{\varphi}{t}\Big|_v = -\frac{\varphi}{v}\Big|_t \div \frac{t}{v}\Big|_\varphi; \quad \ldots\ldots\ldots \quad (83)$$

or a diagonal passage is equivalent to going round the outside and back again. This enables us to write down four other relations.

When the fundamental equations used by a writer are of the first order, they can be written out at once in the required form given by substitution from (82). If they are of the second order, all possible forms can be classified for reproduction with certainty by a mnemonic contrivance analogous to the above.

The chief trouble a layman experiences in following a writer using the analytical method is not in understanding the deductions, but in connecting the process of development used with that he has been in the habit of following.

To such the hint contained above (which can be expanded) may be of service.

DISCUSSION.

Prof. D. S. Jacobus.—This is a graphical method of working out problems which ordinarily are worked out analytically. In the beginning of the paper the statement is made: "In the course of several years a great number of problems were brought under the writer's notice, and treated by the method of transfers, as

the only one by which the results could be rendered intelligible." Now if in addition to all of this theoretical work, the practical problems above referred to had been worked out, and if it was shown that this method was the only one that could handle them intelligently, the paper would be of much greater importance to users of the more purely algebraic methods of thermodynamics. I therefore suggest that if such problems are at hand they be incorporated in the paper.

The theory of ice-making machines is old. Ledoux wrote his thesis in 1878, and the latter is a complete mathematical theory covering the ice machines of to-day, so far as is possible with the experimental data of their performance thus far available. On page 195 we have a general formula, which simply amounts to the addition of the thermodynamical steam-engine economy to the thermodynamical economy of the compressor of the ice-making machine. This is an unnecessary complication. If we wish to show the maximum theoretical economy of an absorption machine such an equation may be employed. In the revision of the work of Ledoux we tried to use a formula of this form to interpret the losses intelligently, and abandoned it because it departs too much from the practical conditions.

What I desire to lay special stress on is the statement in regard to practical problems that can be solved only by the methods advanced in this paper. In our experience we have met with no problems that cannot be solved by ordinary analytical methods.

The graphical method is advanced as one which will save considerable labor in solving a problem. The areas of certain curves may be determined by means of a planimeter instead of by integration, and a saving of time effected in this way; and there will also be less danger of large errors creeping into the work. If, however, a person is thoroughly familiar with analytical methods, it is a small matter to work out the theoretical efficiency of any machine, and the saving by the graphical method will not be appreciable, except where a number of similar problems are to be worked out.

*Mr. George Richmond.**—My choice of language has been singularly unfortunate if it fairly conveys the impression of hostility to analytical methods. Nothing could have been more foreign to my purpose than an attempt to prove the existence

* Author's Closure, under the Rules.

of graphical or geometrical problems which cannot be solved by analysis, nor can I agree with the speaker that such an attempt would have had any utility for "users of algebraic methods" or others, and it would seem that his desire to lay special stress on the statements in question should have been moderated by the entire absence of proof of their existence, and by the reflection that the stupidity of a writer, when proven, is inconclusive, if not immaterial, to any question concerning the subject matter under consideration.

As stated on the first page, these notes originated in the necessity of discussing thermodynamic relations on elementary principles, for which purposes analysis was not *incompetent*, but *unavailable*. By the development of the simplest analytical relation it was found practicable to obtain and discuss the more frequently occurring results with the aid of elementary mathematics only, and to represent them by easy graphical constructions, thus placing the subject within the reach of those unable to pursue the analytical methods. Incidentally the transition to these latter is facilitated, for a knowledge of the more elementary notions of the calculus suffices to express easily seen geometrical relations, and to that extent it is also an aid to the more advanced student. It is believed that a perusal of the paper will disclose sufficient practical examples for the purpose in hand. But the subject of graphical methods need not be discussed, since few would be willing to accept for them the limited *rôle* assigned by the speaker, nor is the verdict on this narrow basis claimed to be the result of experience.

With respect to Equation 13, Professor Jacobus is probably in error as to his application of it to the absorption machine. As stated subsequently, in its proper place this represents among other things the product of the engine and compressor efficiencies, the only question in point being the method of deriving it, which indeed may be open to criticism. It was considered important to establish it on the broadest possible ground as representing the general principle of equivalent transfer, thus including all forms of the refrigeration process, however conducted, and independent of their mechanical or chemical details, for the reason that considerable confusion exists on this point.

I do not yield to the speaker in admiration for the work of

Ledoux, nor is this admiration sensibly diminished by the presence of an occasional mathematical "bull," or thermodynamic backsliding; errors which, in view of the mass of valuable original work, may very readily be condoned; but whether an ingenious elaboration of them is entitled to the same indulgence may be open to question.

Ledoux's theory of the absorption machine is a singular mixture of error, truth, and error expressed in terms of truth. He apparently regards the second law of thermodynamics as a statement of the practical operation of the steam engine, and as not applicable to the absorption machine. There being in this case no visible steam engine, there need be no corresponding rejection of heat; in other words, he holds that the total energy of each unit of heat supplied ought to be utilized. Any possible ambiguity as to his position is removed by reference to Table X., page 151, the sixth column of which gives the value of the ratio $\frac{h}{H}$ according to his theory. Expressed in ice capacity, this column gives as the theoretical ice-producing capacity of one pound of coal numbers ranging from 536 POUNDS TO 265 POUNDS!! Nor is this the extreme production on the Carnot cycle, but is considerably reduced by the conditions imposed in passing to what is named in this paper the third cycle. These results represent the equation;

$$\frac{h}{H} = 1 \times n \frac{T_2}{T_o - T_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad A$$

n being the factor for converting the first cycle to the third. If we assume that the heat supplied to the absorption machine is subject to the second law, and the same proportion of it is utilized as in an engine running on the second cycle, then the first factor of Equation A, instead of being 1, would be:

$$m \frac{T_1 - T_o}{T_1},$$

m being the factor for converting the first cycle to the second, and, like n, determinable on purely thermodynamical principles. Assuming .9 as the approximate value of m, this would reduce the results from 536 and 265 to 77 and 25 respectively, which numbers do not depart so much from the practical results

under the assumed conditions as to require the abandonment of Equation 13, from which they are now derived. In view of the foot-note concurrence in the theory of Ledoux by his distinguished revisers, and the present emphatic endorsement of his work by one of them, it seems clear that Equation A, and not Equation 13, is the one to which my critic has reference, and to which, and which alone, his remark very correctly applies.

The absorption machine is subsequently brought into line by the statement that the rejection of heat (though not a thermodynamic necessity) is practically unavoidable, and the practical precepts deduced are in accordance with this view of the case. For example, the advantage of keeping the temperature of the absorber as high as possible is not only inferred, but tables of performance are given in which, other conditions being identical, a higher temperature in the absorber invariably gives higher efficiency. If the absorption machine is really a form of heat engine subject to the second law, its increase of efficiency by raising the temperature of heat rejection at any point would seem to call for explanation rather than insistence.

DXV.*

STRAINS IN THE RIMS OF FLY-BAND WHEELS PRODUCED BY CENTRIFUGAL FORCE.

BY JAMES B. STANWOOD, CINCINNATI, O.

(Member of the Society.)

THE strains developed in fly-wheels and pulleys are of an extremely complex nature, so that the numerous rules and formulæ employed for proportioning them are almost entirely empirical in character. Experience and judgment have dictated largely the thickness of the rim, while the eye has played an important part in determining the shape and taper of the arms.

In text-books on machine design are found analyses of the strains in pulley arms due either to the pull of belt, the inertia of the rim, or the centrifugal pull on the arms due to weight of rim, etc. These text-books also state that the strength of the rim is not affected by its thickness as regards centrifugal force; for with an increase of thickness there goes an increase of weight with a corresponding increase of centrifugal force and area of cross-section to resist it. From this reasoning wheels of good metal, perfectly true and in good running balance, are only limited in speed by a periphery velocity, roughly assumed at about a mile per minute, or 88 feet per second; a speed giving a very low strain per square inch of rim —to wit, about 800 lbs. per square inch of rim cross-section.

Yet in view of these statements we find wheels bursting at low speed, others running safely at high speed.

In saw-mill practice, where belts travel at high speed, bursting pulleys have given so much trouble, that heavier rims and arms for this service have become common when cast-iron wheels are used. Sometimes even solid disc wheels are employed.

In electric lighting plants many receiving and tightening

* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the Transactions.

pulleys have failed, causing serious or casual disaster, according to circumstances.

Within a few years very large fly-band wheels with wide thin rims have taken the place of fly-wheels with square rims and have also been operated at very high speed. The writer knows of one case where the periphery velocity on a 17′–9″ wheel is over 7,500 feet per minute.

In band saw-mills the blade of the saw is now operated suc-

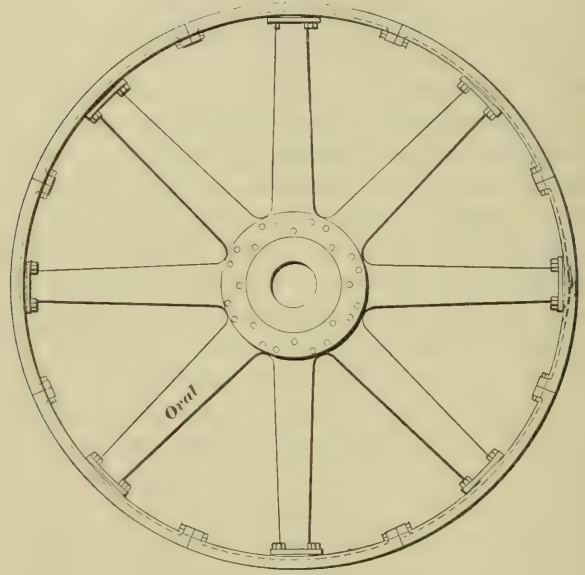


Fig. 107.

cessfully over wheels 8 and 9 feet in diameter, at a periphery velocity of 9,000 to 10,000 feet per minute. These wheels are of cast iron throughout, of heavy thickness, with a large number of arms. Who would dare to operate an ordinary 9-foot pulley at that speed?

In shingle machines and chipping machines where cast-iron discs from 2 to 5 feet in diameter are employed, with knives inserted radially, the speed is frequently 10,000 to 11,000 feet per minute at the periphery.

In view of the disasters so common of late to large band fly-wheels running at slower speed than these, it seems probable

that the strains set up in wheels by centrifugal force have not been fully considered.

Last spring the writer was one of three experts, called in to decide upon the cause of a serious fly-wheel accident. From the testimony submitted by a well-known builder of large wheels, he was led to investigate a special strain developed by centrifugal force in band-wheel rims. This strain is due to the fact that all materials have elasticity, and stretch when under strain. The wheel in question was 22 feet in diameter, 50 inches face, and

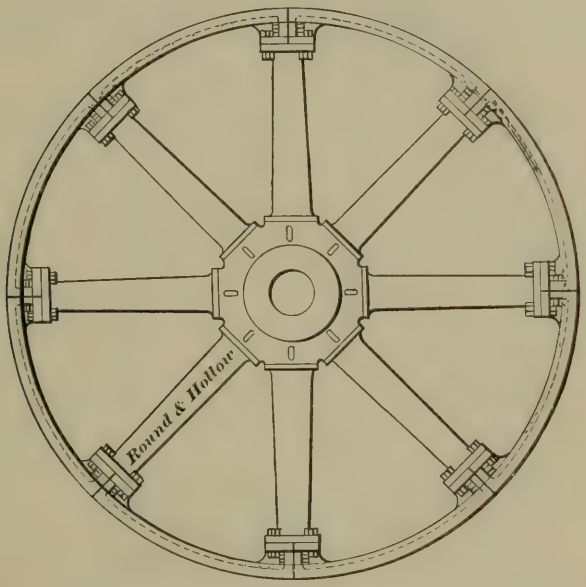


Fig. 108.

had a periphery speed of 5,000 feet per minute. It was built in sections, as so many large wheels usually are (see Fig. 107). The segments were secured to arms in such a manner that the segmental joints lay half way between the arms. This construction was criticised by the aforesaid builder, who indicated by a sketch (see Fig. 108) a better method. This formed the starting point for the investigation, which the writer wishes to submit for discussion.

A thin annular ring (Fig. 109) 1 inch wide and t inches thick, revolving about a central axis A, is subjected to a simple tensile strain, similar in every respect to that found in a boiler shell,

its amount per square inch T being $\frac{V^2}{10}$, when V equals velocity of rim, in feet, per second. This can be shown as follows :

Let r = radius of ring in inches.

R = " " " feet = $\frac{r}{12}$

V = velocity " " " per second.

The tensile strain T in pounds per square inch of rim section,

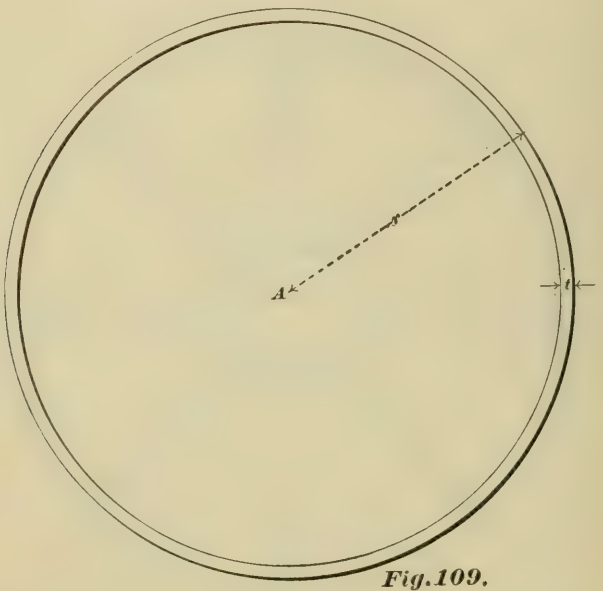


Fig. 109.

due to bursting pressure per square inch p with a ring thickness t in inches, is :

$$T = \frac{pr}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Each pound weight of ring exerts a bursting pressure due to centrifugal force =

$$\frac{V^2}{32.2\ R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or for each inch in length of ring it will be

$$\frac{V^2}{32.2} \times \frac{12}{r} \times .261\ t = p \quad . \quad . \quad . \quad . \quad . \quad (3)$$

substituting in (1) we have:

$$T = \frac{\frac{V^2}{32.2} \times \frac{12}{r} \times .261\, t \times r}{t} = \frac{V^2}{10} \text{ nearly} \quad . \quad . \quad . \quad (4)$$

Under this strain the ring expands. If C be taken as the modulus of elasticity, this expansion will amount to $\frac{.314\ V^2 d}{C}$ in the circumference of the ring.

If arms are inserted in the ring, and are supposed at first to have no weight and to be rigid, with no elasticity, their effect

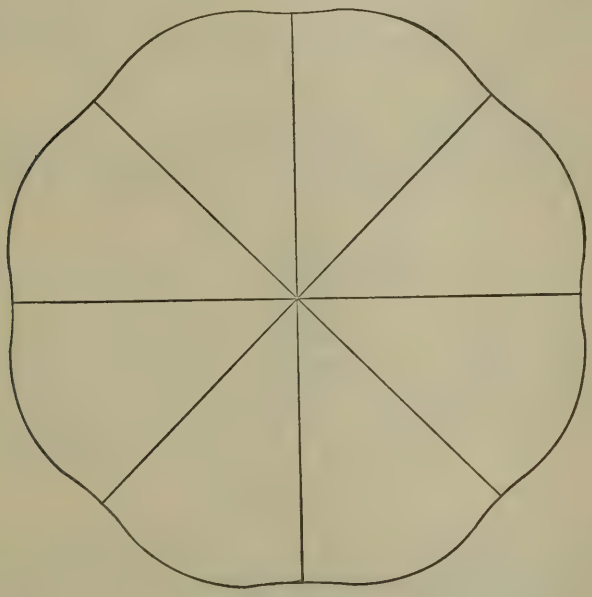


Fig. 110.

will be to pull the expanded ring into its original diameter at the arms. It will then have the form diagramatically exaggerated, as shown by Fig. 110.

Under these conditions what will be the strain upon the ring? The ring between each arm resembles now a uniformly loaded rectangular beam fixed at both ends; it is also under a tensile strain of $\frac{V^2}{10}$ pounds.

The greatest strain in pounds per square inch F to which any fibre is subjected, can be expressed generally thus:

$$F = \frac{pl^2}{2t^2} + \frac{V^2}{10} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where l represents in inches the distance from center to center of arms, p the uniform load in pounds per square inch on the length l, and t = thickness of rim in inches. The width is assumed to be unity.

This formula can be expanded by substituting for p its value $\frac{V^2}{32.2} \times \frac{24}{d} \times .261\,t$ (from 3) where d = diameter of ring in inches $= 2r$, and for l its value $\frac{3.14\,d}{N}$ (6) where N = number of arms. Then

$$F = \frac{\frac{3.14^2 d}{N^2} \times \frac{V^2}{32.2} \times \frac{24}{d} \times .261\,t}{2t^2} + \frac{V^2}{10} \quad . \quad . \quad . \quad . \quad (6)$$

$$= \frac{.95\,d\,V^2}{N^2 t} + \frac{V^2}{10} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\text{or } F = V^2\left(\frac{.95\,d}{N^2 t} + \frac{1}{10}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\text{or } t = \frac{.95\,d}{N^2\left(\frac{F}{V^2} - \frac{1}{10}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

But the ends of the arms do not remain rigid; the arms themselves expand longitudinally under the influence of their own centrifugal force, and they are also elongated by the strain outward imposed upon them by the expanding ring. In fact a compromise is effected; the arm stretches out to the ring, the ring yields in towards the arm, and the bending action in the ring depends upon this undeterminate amount. It appears, therefore, that the strain F cannot equal the value as derived by equation (8). By a careful comparison of rim thicknesses, as determined by equation (9), with good practice t is found to be too large On the contrary, $\frac{t}{2}$ gives consistent

results, and reasonably so, for roughly the arms can be assumed to expand one-half of the amount that the ring expands diametrically. When the arms are few in number, and of large cross section, the ring will be strained transversely to a greater degree than with the same number of lighter arms. To illustrate the necessary rim-thicknesses for various rim velocities, pulley diameters, number of arms, etc., the following table is submitted, based upon the formula

$$t = \frac{.475\, d}{N^2\left(\frac{F}{V^2} - \frac{1}{10}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

This is half the value given by (9), and the value of F is taken at 6,000 lbs. per square inch.

THICKNESS OF RIMS IN SOLID WHEELS.

Diameter of pulley in inches.	Velocity of rim in feet per second.	Velocity of rim in feet per minute.	No of arms.	Thickness in inches.
24	50	3,000	6	$\frac{2}{3}$
24	88	5,280	6	$1\frac{1}{16}$
48	88	5,280	6	$1\frac{5}{16}$
108	184	11,040	16	$2\frac{1}{2}$
108	184	11,040	36	$\frac{1}{2}$*

If the limit of rim velocity for all wheels be assumed to be 88 feet per second, equal to 1 mile per minute, $F = 6{,}000$ lbs.; the formula becomes

$$t = \frac{.475d}{.67N^2} = 0.7\,\frac{d}{N^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

When wheels are made in halves or in sections, the bending strain may be such as to make t greater than that given above. Thus, when the joint comes half way between the arms, the bending action is similar to a beam supported simply at the ends, uniformly loaded, and t is 50% greater. Then the formula becomes

$$t = \frac{.712d}{N^2\left(\frac{F}{V^2} - \frac{1}{10}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

* These are the calculated thicknesses for a band saw-wheel 9 feet in diameter with 390 revolutions per minute. The actual thicknesses as made were found to be $2\frac{1}{2}$ inches with 16 arms, and $\frac{3}{4}$ inches with 36—$1\frac{1}{8}$ inches steel arms.

or for a fixed maximum rim velocity of 88 feet per second, and $F = 6{,}000$ lbs.,

$$t = \frac{1.05d}{N^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

It is a fact that wheels do spring out at the joint when cast in halves or sections; for the writer has frequently tested them when they have shown this state of affairs. For this reason the construction for segmental wheels, shown by Fig. 108, is preferable to that shown by Fig. 107.

Wheels in halves, if *very thin rims* are to be employed, should

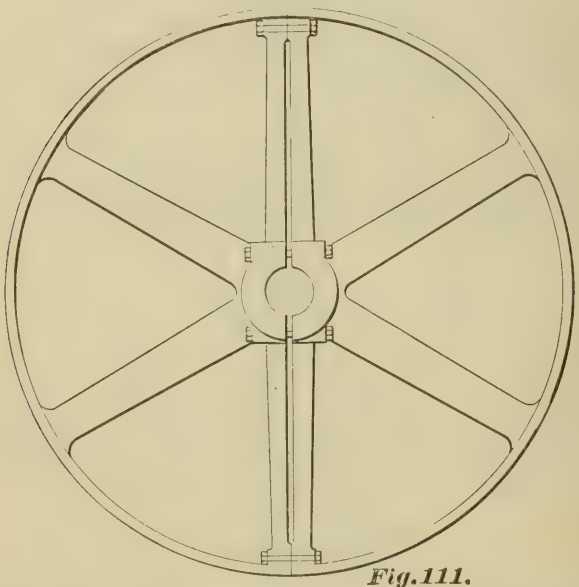


Fig. 111.

have double arms along the line of separation (Fig. 111). Compare the thickness of the rim of a wheel made in segments or in halves, the joint half-way between the arms (Fig. 107), with the thickness of the rim as constructed in Fig. 108. For example, take a 20-foot wheel at 88 feet rim velocity per second, with 10 arms. When constructed according to Fig. 107, t must be $2\frac{1}{2}$ inches; according to Fig. 108, $1\frac{1}{16}$ inches.

Attention should be given to the proportions of large receiving and tightening pulleys. The thickness of rim for a 48-inch wheel (shown in table) with a rim velocity of 88 feet per second, is $\frac{15}{16}$ inch. This should be carefully noted. Many wrecks

have been caused by the failure of receiving or tightening pulleys whose rims have been too thin.

A word of caution should be given to engine builders and engineers. Wheels may be specified to be made too light in weight; for with a given diameter and weight there is a minimum safe-weight dependent upon the principles already set forth. Fly-wheels calculated for a given coefficient of steadiness are frequently lighter than the minimum safe-weight. This is true especially of large wheels.

A rough guide to the minimum weight of wheels can be deduced from our formulæ. The arms, hub, lugs, etc., usually form from one-quarter to one-third the entire weight of the wheel. If b represent the face of a wheel in inches, the weight of the rim (considered as a simple annular ring) will be

$$w = .82\ dtb \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

If the limit of speed is 88 feet per second, then for solid wheels

$$t = 0.7\ \frac{d}{N^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

For sectional wheels (joint between arms)

$$t = \frac{1.05d}{N^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Substituting in (14) we have: weight of rim for solid wheels,

$$w = \frac{.57\ d^2 b}{N^2} \text{ in pounds} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Weight of rim in sectional wheels with joints between arms:

$$w = \frac{.86\ d^2 b}{N^2} \text{ in pounds} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Total weight of wheel: for solid wheel,

$$W = \frac{.76\ d^2 b}{N^2} \text{ to } \frac{.86\ d^2 b}{N^2} \text{ in pounds} \quad . \quad . \quad (17)$$

For segmental wheels with joint between arms:

$$W = \frac{1.05\ d^2\ b}{N^2} \text{ to } \frac{1.3\ d^2\ b}{N^2} \text{ in pounds} \quad . \quad . \quad (18)$$

This investigation has not the advantage of extreme accuracy, but it tends to show a relation which ought to be observed. The constants used may be modified by further experience.

The value of $F = 6{,}000$ lbs., is taken at one-sixth of Rankine's ultimate breaking strength of cast iron when under transverse strain. The factor of safety is, therefore, 6. It should be remembered that in wheels this factor can be rapidly diminished; thus the strain varies nearly as the rim velocity squared, and if the velocity is doubled, the strain is quadrupled, and the factor of safety is reduced from 6 to less than 2.

DISCUSSION.

Prof. Gaetano Lanza.—In view of the fact that the bursting of fly-wheels is attended with very disastrous consequences, it seems to me that it is time that calculation should be made to supersede empiricism in their design. Hence any addition to our knowledge of the actual distribution of the stresses in a fly-wheel is valuable.

Mr. Stanwood takes up one phase of the subject, and points out the fact that there is a stress in the rim of a fly-wheel due to the bending of the portion of the rim between two arms, in addition to the centrifugal tension in the rim, and that, the larger the number of arms, the less will be the stress due to the bending of the rim.

When he undertakes to determine the stress due to bending he assumes, as I understand his paper:

First. That, were it not for the stretching of the arms, the portion of the rim between two successive arms would be in the condition of a beam fixed in direction at the ends.

Second. That the number of the arms is such that no great error will be made in the stress by considering the portion of the rim between two successive arms to be straight.

Third. That the stretching of the arms in a radial direction will be such as to cause the stress in the rim due to bending to be one-half what it would be if the arms did not stretch at all.

I shall make no comments upon the first nor upon the second

assumption, but will say, in regard to the third, that the arguments presented by Mr. Stanwood do not seem to me to be conclusive.

It is plain that the value of t given by Mr. Stanwood in equation (9) should be diminished in consequence of—

First. The stretching of the arms due to their own centrifugal tension, which may approach, but will not exceed (as can be easily shown) one-third of the stretch required in order that there should be no bending of the rim.

Second. The stretching of the arms due to the load thrown on them by the centrifugal force in the rim. It is very difficult to say how much this latter is, and it seems to me at least probable that it varies with the relative cross-sections of arm and rim.

Next, in regard to the value of t given in equation (12); if we consider the portion of the rim between the arm and the joint as a cantilever, we obtain

$$t = \frac{1.424\, d}{N^2\left(\frac{F}{V^2} - \frac{1}{10}\right)},$$

whereas the value given by Mr. Stanwood in equation (12) is just one-half of the above.

I do not suppose that he adopts this value on account of the stretching of the arms, and hence I imagine that he considers that the other half of the bending moment, which he has neglected, will be taken up by the bolts and flanges. Without commenting further upon Mr. Stanwood's paper, except to say that 6,000 pounds per square inch seems to me to be rather a large value to use for working strength of cast iron in this form, I will call attention to another phase of the fly-wheel problem which, I believe, is often disregarded by builders, and to this neglect are, I believe, chargeable more or less disasters.

What I have to say refers to large fly-wheels made in sections, the sections being bolted together.

Sometimes, as Mr. Stanwood says, this bolting is done halfway between two arms, as shown in Fig. 107, and sometimes over the arms, as shown in Fig. 108. In the latter case, however, the amount by which the rim of the wheel projects beyond the arms, in a direction parallel to the shaft, is so great that the outer portion receives little or no reënforcement from the attachment of the rim to the arm.

In both these cases, it is almost invariably the case that the joint is the weakest part of the structure, and that, in the case of a number of existing fly-wheels, if any one will figure in detail the stresses in the different parts of the joint, he will find that a very small factor of safety has been used in their design.

I will therefore proceed to discuss the mode of calculation of such a joint, assuming at first that the joint is half-way between two arms, as shown in Fig. 107 in the paper.

Let F_0 represent the total hoop tension in the rim, and ρ_0 the distance from the centre of the shaft to its point of application; ρ_0 will, of course, be very nearly equal to the radius of the wheel, minus half the thickness of the rim in the case of rims without heavy ribs.

In this case it is not, as a rule, possible to place the bolts in such a position that their axes are at the distance ρ_0 from the axis of the wheel; hence it follows that the bolts are liable to a stress considerably greater than F_0.

Now, inasmuch as the fastenings are not in line with the force F_0, a bending moment arises, and two extreme cases are conceivable.

First. That the bending is taken up by the fastenings, *i.e.*, the bolts and flanges, and not by the rim.

Second. That the bending is taken up by the rim, and not by the bolts.

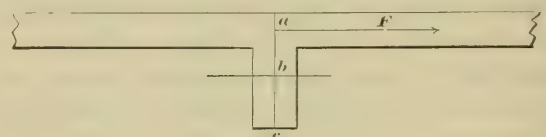


Fig. 187.

The first case would occur when the bolts are set up very tightly, and when the rim and flanges are very stiff, so that if a (Fig. 187) represents the point of application of F_0, and b the axis of the bolt or bolts, and c the lowest point where the flanges come in contact, and S the total stress in the bolts, then

$$S = F_0\left(\frac{ac}{bc}\right).$$

In this case there is a bending moment in the flange at b equal to $F_0(ab)$, but there is no bending moment in the rim.

The second case would arise if the two parts of the rim did

not touch each other, or at least did not bear against each other.

In this case the total stress in the bolts is only F_0, but the bending moment $F_0(ab)$ is taken up by the rim.

In the actual case the stresses may be either of the above, or anywhere intermediate between them, and are liable to vary in their distribution according to the speed and the consequent amount of yielding of the different parts.

The proper method of procedure is to design the pulley in such a way that the bolts and flanges are strong enough to resist the stress if it occurs as described in the first case, and that the rim and flanges are strong enough to resist the stresses if they occur as described in the second case.

Of course, we might first calculate the greatest bending moment that the rim could support safely, which in the case of thin rims will be small, and then figure the bolts to take up the rest, but it would be better to follow the directions I have given above.

In order to strengthen the rim and the flanges at the joint, either there should be a sufficient number of ribs on the inside of the rim, or else a number of short ribs should be cast on the inside of the rim extending back a short distance from the joint. Nevertheless, in whatever manner the wheel is designed, all these bolt stresses, and the fibre stresses due to bending in rim and flanges at the joint, should be figured and kept within safe limits.

When the rim is made as shown in Fig. 108 of the paper, with the joints over the arms instead of between them, there is often so large a projection of the rim beyond the arms, in a direction parallel to the shaft, that the arms furnish little or no aid to the outer portion of the joint in the rim, and then we should figure the joints for their outer portions at any rate, just as has been stated for the case where the joints come between the arms.

In the above discussion I have confined myself to the stresses due to centrifugal force, because these are the limitations prescribed by the title of Mr. Stanwood's paper; but in order to design the wheel properly we need to take into account in our calculations also the stresses produced by the pull of the belt, or, in the case of gears, by the pressure of the gear teeth. If designers will figure correctly all the stresses that are liable to

occur in all parts of the joints, I believe we shall have less trouble with fly-wheels.

Mr. John H. Cooper.—The great importance of a rule for finding the stress put upon the rim of a fly-wheel by centrifugal force alone, induces me to send you a formula used at Southwark Foundry. It is this :

$$S = \frac{.00005427\ D.N.^2W}{2A},$$

in which S = stress per square inch on rim ;
A = area of rim (one section) in square inches ;
D = diameter of wheel in feet ;
N = number of revolutions per minute ;
W = weight of rim in pounds.

When we know the stress put upon the rim by centrifugal force, pure and simple, we are safe thus far ; next we must decide upon a factor of safety, which must be modified by the character of the work done by the wheel, that is, as to the magnitude of the concussions to which it is to be subjected. Allowance must also be made for joints, if the rim have any, as well as for possible shrinkage strains caused by incongruous mixtures of iron and by sudden or unequal cooling.

*Mr. Jas. B. Stanwood.**—The formula submitted by Mr. Cooper gives exactly the same result as formula (4) in the paper, $T = \frac{V^2}{10}$; for in his formula if we substitute equivalent values for W, A, and N expressed in terms of the thickness t and breadth b of rim in inches, and velocity V in feet per second, we get $S = \frac{V^2}{10}$ nearly. (For $W = 3.1416 \times 12Dtb \times 0.261$; $A = tb$; $N = \frac{60\ V}{3.1416}$.)

This is the rule to which objection is made in the paper, in that it gives no clew to the strain produced by the inward pull of the arms. It gives the same strain per square inch of rim section for a rim 4 inches thick as for one $\frac{1}{8}$ inch thick, other things being equal. Mr. Cooper calls attention to the strains produced by shrinkage and concussion in the joints in the wheel, but does not indicate how to determine these strains. In the analysis

* Author's Closure, under the Rules.

in the paper the action of the joints is taken into consideration, while for the uncertain strains due shrinkage and concussions, allowances must be made as is done for all cast-iron structural work. By the analysis presented a strain is pointed out, hitherto unnoticed, which has baffled all allowances usually covered by factors of safety.

The remarks of Professor Lanza open a field for further investigation upon which the writer cannot now find time to enter. He hopes to present the results of experiment and calculation in another paper to be presented hereafter, which shall cover the points thus raised.

DXVI.*

HYDRAULIC REACTION MOTORS.

BY DE VOLSON WOOD, HOBOKEN, N. J.

(Member of the Society.)

1. So much has been written upon this subject that it may seem that nothing more of importance in regard to the theory remains to be said. But I have not been fully satisfied with what I found in books, and have, therefore, sought to supply certain defects. About forty-five years ago M. Poncelet made a solution which, for its thoroughness and the directness of its analysis, has become classical (*Comptes Rendus*, 1838). But that writer neglected the frictional (and other) resistances within the wheel, and assumed that the buckets, or passages in the wheel, were constantly full. The former is an important element in the theory, and makes the analysis but little more complicated; while the latter, if true at all, will be so only for a certain velocity.

Weisbach, in his *Hydraulic Motors*, gives a solution in which frictional resistances are involved, and the sections of the stream at the outlet of the supply chamber, the entrance into the wheel, and all the sections of the buckets, are determined when the wheel runs for best efficiency. If any of the sections in the wheel as constructed, are less than those determined by theory, the theory will not apply, while if all are larger, except those at exit from the wheel, it is assumed that the stream will adjust itself to the proper size by the formation of eddies and whirls, although the effective angles may thus be changed. The formulas, however, given by Weisbach are so complex that but little practical knowledge can be gained from their general discussion. I have, therefore, assumed that the wheels have about the proportions made for commercial purposes, and deduced certain

* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

numerical results which are entered in tables. A simple examination of these furnishes certain desirable information.

J. Lester Woodbridge, a graduate of Stevens' Institute, made a solution for a frictionless turbine, assuming that the sections of the stream are coincident with the corresponding sections of the buckets, at first neglecting all considerations of guides in the supply chamber, and after finding the velocity for maximum efficiency, determined the normal section of the passage between the guides at the gate opening. If the normal sections between the guides and of the buckets are the same as the computed values, this solution would be the same as Weisbach's. (*Phil. Mag.*, and *Jour. Frank. Inst.*, 1866.) I have made a solution of this case when friction is involved. I would be pleased to give only the original work I have done, but to make a connected solution and discussion, it seems to be necessary to deduce many formulas more or less familiar.

2. *Notation.*

Let Q be the volume of water passing through the wheel per second.

δ, the weight of unity of volume of the water, or 62½ pounds per cubic foot; then

$\delta Q = W$ will be the weight of water passing through the wheel per second.

h_1 be the head in the supply chamber above the entrance to the buckets (Fig. 113).

h_2, the head in the tail race above the exit from the bucket.

z_1, the fall in passing through the buckets.

$H = h_1 + z_1 - h_2$, the effective head.

U, the useful work done by the water upon the wheel.

R, the work lost by frictional resistances, whirls, etc

μ_1, the coefficient of resistance along the guides.

μ_2, the coefficient of resistance along the buckets.

r_1, the radius of the initial rim.

r_2, the radius of the terminal rim.

ρ, the radius to any point of the bucket.

$n = r_1 \div r_2$, the ratio of the initial to that ot the terminal radius.

V, the velocity of the water issuing from supply chamber.

v_1, the initial velocity of the water in the bucket in reference to the bucket.

v, the velocity along the bucket at any point.

v_2, the terminal velocity in the bucket.

w, the velocity of exit in reference to the earth.

ω, the angular velocity of the wheel.

α, terminal angle between the guide and initial rim = CAB (Fig. 112).

γ_1, angle between the initial element of bucket and initial rim = EAD.

$\gamma_2 = GFI$, the angle between the terminal rim and terminal element of the bucket.

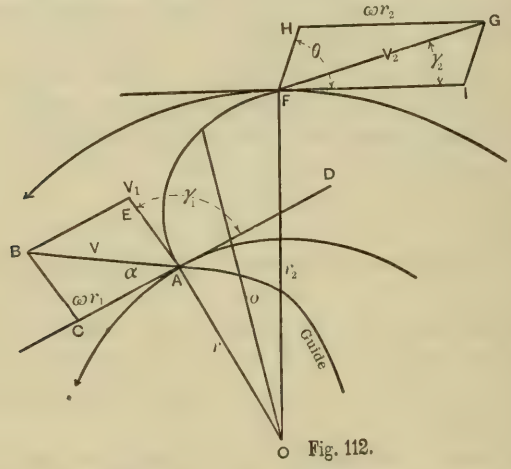


Fig. 112.

$\theta = IIFI$, angle between the terminal rim and actual direction of the water at exit.

p_1, the pressure of water at entrance of the bucket per unit area.

p, the pressure of water at any point of the bucket.

p_2, the pressure of water at exit.

p_a, the pressure of an atmosphere.

$a = cb$, the arc subtending one gate opening (Fig. 115).

a_1, the arc subtending one bucket at entrance (in Fig. 113, a and a_1 appear to be the same, but in practice a_1 is larger than a).

$a_2 = gh$, the arc subtending one bucket at exit.

$K = bf$, normal section of passage, it being assumed that the passages and buckets are *very* narrow.

$k_1 = bd$, initial normal section of bucket.

$k_2 = gi$, terminal normal section.

Y, the depth of K, y_1 of a, and y_2 of k_2.

Then

$$K = Va \sin \alpha\,; \; k_1 = y_1 a_1 \sin \gamma_1\,; \; k_2 = y_2 a_2 \sin \gamma_2, \quad . \quad . \quad . \quad (1)$$

ωr_1 = velocity of initial rim.
ωr_2 = velocity of terminal rim.

3. *General Solution.*

Beginning with the pressure on the top of the supply chamber, the relation between the heads, actual and virtual, will be determined to the point of discharge from the wheel.

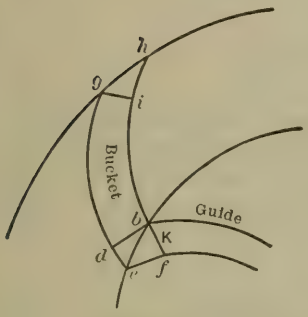


FIG. 113.

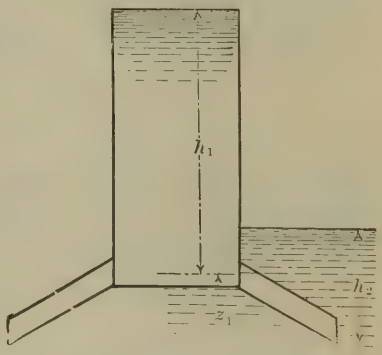


FIG. 114.

The pressure per unit on the upper surface of the supply chamber (Fig. 114) will be that of the atmosphere, or

$$p_a,$$

and the corresponding virtual head in terms of a column of water will be

$$\frac{p_a}{\delta}.$$

The head in the supply chamber above the entrance to the wheel will be

$$h_1\,;$$

therefore the total head above the initial element of the bucket will be

$$h_1 + \frac{p_a}{\delta}.$$

This head produces an actual pressure p_1 at the entrance to the bucket and the velocity V of exit from the guides; hence, according to Bernoulli's theorem, the heads due to the pressure p_1 and velocity V, will equal the former, or

$$h_1 + \frac{p_a}{\delta} = \frac{p_1}{\delta} + \frac{V^2}{2g}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\therefore p_1 = p_a + \delta h_1 - \delta \frac{V^2}{2g}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which will be the theoretical pressure at entrance to the bucket if friction be neglected. Represent the head lost by friction by

$$\mu_1 \frac{V^2}{2g},$$

which must also be overcome by the head in the supply chamber, so that we have, by adding to the second member of (2) and transforming,

$$(1 + \mu_1)\ V^2 = 2gh_1 + 2g\left(\frac{p_a - p_1}{\delta}\right) \quad . \quad . \quad . \quad . \quad (4)$$

The triangle of velocities ABC, Fig. 112, gives

$$V = \frac{\sin \gamma_1}{\sin (\alpha + \gamma_1)} \omega r_1 = \frac{\sin \gamma_1}{\sin (\alpha + \gamma_1)} n \omega r_2 \quad . \quad . \quad . \quad (5)$$

$$r_1 = \frac{\sin \alpha}{\sin (\alpha + \gamma_1)} \omega r_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The relation between the initial and terminal velocities in the bucket involves the velocity of the wheel and the pressure in the bucket.

Let m be an elementary mass at a distance ρ from the axis of the wheel (Fig. 115), then will the centrifugal force be

$$m\omega^2\rho,$$

and if this element by moving a distance ds in the tube also moves outward a distance $d\rho$, the work done by the centrifugal force will be

$$m\omega^2\rho d\rho.$$

If the tube (or bucket) be inclined downward, the work done (or energy acquired) by the weight in falling a distance dz will be

$$mgdz.$$

These two works will be expended in the following ways :

a. Increasing the energy of the water in the tube in reference to the tube by an amount

$$\tfrac{1}{2}\, md\,(v^2).$$

b. In doing work against the difference of pressures on the

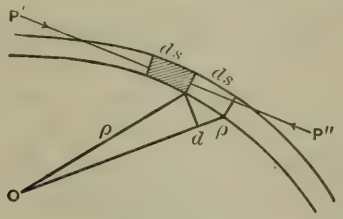


FIG. 115.

two faces of the element, and considering the back pressure p'' greater than the forward pressure p', the work will be

$$mg\,\frac{dp}{\delta},$$

where $dp \div \delta$ is equivalent to a head through which mg would work.

c. In overcoming frictional resistance, the law of which is not well known, but is assumed to vary as the length of the path and square of the velocity, according to which the expression will be

$$\mu d\left(\frac{sv^2}{2g}\right).$$

Hence,

$$mgdz + m\omega^2\rho d\rho = \tfrac{1}{2}\, md\,(v^2) + mg\,\frac{dp}{\delta} + \mu d\left(\frac{sv^2}{2g}\right) \quad . \quad . \quad (7)$$

The integral of the last term is $\mu\,\frac{sv_2^2}{2g}$, but in the turbine the frictional resistance is determined independently of the length of the buckets, so that μ_2 takes the place of μs. The integral of Equation (7) will be

$$z_2 - z_1 + \frac{\omega^2(r_2^2 - r_1^2)}{2g} = \frac{v_2^2 - v_1^2}{2g} + \frac{p_2 - p_1}{\delta} + \mu_2\,\frac{v_2^2}{2g}. \quad . \quad (8)$$

The fall $z_2 - z_1$ is so small in practice compared with the next term of the equation, that it may, and will be, omitted, giving

$$(1 + \mu_2) v_2^2 = v_1^2 + \omega^2 (r_2^2 - r_1^2) - 2g \frac{p_2 - p_1}{\delta}, \quad . \quad . \quad (9)$$

which gives v_2.

At exit the pressure will be

$$p_2 - p_a + \delta h_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The velocity of exit, relative to the earth, will be

$$w^2 = v_2^2 + \omega^2 r_2^2 - 2 v_2 . \omega r_2 \cos \gamma_2. \quad . \quad . \quad . \quad (11)$$

The work done upon the wheel will be the initial (potential) energy of the water less the energy in the water as it quits the wheel, still further diminished by the energy due to frictional losses; or

$$U = \delta Q H - \delta Q \frac{w^2}{2g} - R. \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$R = \mu_1 \delta Q \frac{V^2}{2g} + \mu_2 \delta Q \frac{v_2^2}{2g}. \quad . \quad . \quad . \quad . \quad . \quad (13)$$

A sufficient number of equations have now been established to find, by elimination, the useful work U in terms of the angular velocity ω and known constants; and the efficiency will be U divided by the *theoretical* work the water was capable of doing. Performing the operations, there will be found

$$E = \frac{U}{\delta Q H} = \frac{r_2 \omega}{g H \sqrt{1 + \mu_2}} \times$$

$$\left\{ \frac{\sqrt{1+\mu_2} \left\{ -1 + \frac{\cos \alpha \sin \gamma_1}{\sin (\alpha + \gamma_1)} \left(\frac{r_1}{r_2} \right)^2 \right\} r_2 \omega + \cos \gamma_2}{\sqrt{2gH + \left\{ 1 - \left(\frac{2 \cos \alpha \sin \gamma_1}{\sin (\alpha + \gamma_1)} + \mu_1 \frac{\sin^2 \gamma_1}{\sin^2 (\alpha + \gamma_1)} \right) \left(\frac{r_1}{r_2} \right)^2 \right\} r_2^2 \omega^2}} \right\} \quad (14)$$

$$= L \left[- M^2 r_2 \omega + \cos \gamma_2 \sqrt{2gH + M^2 r_2^2 \omega^2} \right] r_2 \omega, \quad . \quad . \quad . \quad (15)$$

when

$$\left.\begin{aligned} L &= \frac{1}{gH\sqrt{1+\mu_2}}. \\ -M^2 &= \sqrt{1+\mu_2}\left[-1+\frac{\cos\alpha\sin\gamma_1}{\sin(\alpha+\gamma_1)}\left(\frac{r_1}{r_2}\right)^2\right], \\ N^2 &= 1-\left(\frac{2\cos\alpha\sin\gamma_1}{\sin(\alpha+\gamma_1)}+\mu_1\frac{\sin^2\gamma_1}{\sin^2(\alpha+\gamma_1)}\right)\left(\frac{r_1}{r_2}\right)^2 \end{aligned}\right\} \quad (15a)$$

For maximum efficiency make $dE \div d\omega = 0$ in (15) and solve for ω, calling this particular value ω', then

$$\omega' = \frac{\sqrt{gH}}{r_2}\sqrt{\frac{M^2-\sqrt{M^4-N^2\cos^2\gamma_2}}{N^2\sqrt{M^4-N^2\cos^2\gamma_2}}}, \quad . \quad . \quad (16)$$

which value substituted in Equation (15) will give for the maximum efficiency,

$$E_{max.} = \left(M^2-\sqrt{M^4-N^2\cos^2\gamma_2}\right)\frac{1}{N^2\sqrt{1+\mu_2}}. \quad . \quad (16a)$$

Then Equations (5) and (6) become

$$V = \frac{\sin\gamma_1}{\sin(\alpha+\gamma_1)}\omega' r_1, \quad . \quad . \quad . \quad . \quad . \quad (17)$$

$$v_1 = \frac{\sin\alpha}{\sin(\alpha+\gamma_1)}\omega' r_1. \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Also from (9), (10), (4), (17), (18),

$$v_2 = \sqrt{\frac{1}{1+\mu_2}} \times \sqrt{2gH+\left(r_2^2-2\frac{\cos\alpha\sin\gamma_1}{\sin(\alpha+\gamma_1)}r_1^2-\mu_1\frac{\sin^2\gamma_1}{\sin^2(\alpha+\gamma_1)}r_1^2\right)\omega'^2}. \quad (19)$$

The normal sections of the buckets will be

$$K = \frac{Q}{V}; \quad k_1 = \frac{Q}{v_1}; \quad k_2 = \frac{Q}{v_2}; \quad k = \frac{Q}{v}. \quad . \quad . \quad (20)$$

The depths of those sections will be

$$Y = \frac{K}{A \sin \alpha}, \quad y_1 = \frac{k_1}{a_1 \sin \gamma_1}, \quad y_2 = \frac{k_2}{a_2 \sin \gamma_2}. \quad . \quad (21)$$

DISCUSSION.

4. *Three simple systems are recognized,*

$r_1 < r_2$, called *outward flow.*
$r_1 > r_2$, called *inward flow.*
$r_1 = r_2$, called *parallel flow.*

The first and second may be combined with the third, making a *mixed* system. The third, in theory, is really an inward or outward flow, with an indefinitely narrow crown, although the analysis applies to a parallel flow wheel, in which the width is indefinitely small, and depth small compared with the total head.

5. *Value of γ_2, the quitting angle.*

Equations (14) and (15) show that the efficiency is increased as $\cos \gamma_2$ is increased, or as γ_2 decreases, and is greatest for $\gamma_2 = 0$. Hence, theoretically, the terminal element of the bucket should be tangent to the quitting rim for best efficiency. This, however, for the discharge of a finite quantity of water, would require an infinite depth of bucket, as shown by the third of Equations (21). In practice, therefore, this angle must have a finite value. The larger the diameter of the terminal rim the smaller may be this angle for a given depth of wheel and given quantity of water discharged. Theoretical considerations then would require, for best efficiency, a very large diameter for the quitting rim, and a very small angle, γ_2, between the terminal element of the bucket and the rim; but commercial considerations require some sacrifice of best efficiency to cost, so that a smaller diameter and larger angle of discharge is made. If wheels are of the same diameter and depth, the inward flow wheel requires a larger angle of discharge for the same volume of water than the outward flow, since the discharge rim will be smaller in the former than in the latter wheel, and the velocity v_2 will also be less, as shown by Equation (19). In practice γ_2 is from 10° to 20°.

6. *Relation between γ_2 and ω'.*

Equation (16) when put under the form

$$\omega' = \frac{\sqrt{gH}}{Nr_2}\sqrt{\frac{1}{\sqrt{1-\frac{N^2\cos^2\gamma_2}{M}}}-1} \quad . \quad . \quad . \quad (22)$$

shows that ω' increases as γ_2 decreases, and is largest for $\gamma_2 = 0$; that is, in a wheel in which all the elements except γ_2 are fixed, *the velocity of the wheel for best effect must increase as the quitting angle of the bucket decreases.*

If the terminal element be radial, then $\gamma_2 = 90°$, and Equation (22) gives $\omega' = 0$; that is, for maximum (or minimum) efficiency the wheel must be at rest, but no work will be done.

7. *Values of $\alpha + \gamma_1$.*

If $\alpha + \gamma_1 = 180°$, and α and γ_1 both finite, then will M and N in (15a) both be infinite; but Equation (5) gives

$$\omega = \frac{\sin 180°}{\sin \gamma_1} \cdot \frac{V}{r_1} = 0; \quad . \quad . \quad . \quad . \quad . \quad (23)$$

that is, the wheel will have no motion, and no work will be done. This condition requires that the terminal element of the guide

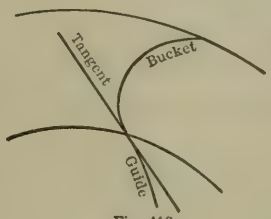


Fig. 116

and the initial element of the bucket have a common tangent, Fig. 116, so that the stream can flow smoothly from the former into the latter only when the wheel is at rest.

If $\alpha + \gamma_1$ exceed 180°, ω' would be negative, and it would be necessary for the wheel to be rotated backwards in order that the water should flow smoothly from the guide into the bucket.

It follows, then, that $\alpha + \gamma_1$ must be less than 180°, but the best relation cannot be determined by analysis; however, since the water should be deflected from its course as much as pos-

sible from its entering to its leaving the wheel, the angle α for this reason should be as small as practicable.

8. *Values of* α.

If $\alpha = 0$, Equation (14) will reduce to

$$E = \frac{\omega}{gH\sqrt{1+\mu_2}}\left[\sqrt{1+\mu_2}(-r_2^2+r_1^2)\,\omega + r_2\cos\gamma_2\sqrt{2gH+(r_2^2-2r_1^2-\mu_1 r_1^2)\,\omega^2}\right] \quad . \quad (24)$$

which is independent of γ_1; hence, for this limiting case, the efficiency will be independent of the initial angle of the bucket. This is because the water enters the wheel tangentially and therefore has no radial component that would give an initial velocity in the bucket; and Equation (18) shows that the initial velocity v_1 would be zero, while (17) shows that the velocity of the initial rim must equal that of the water flowing from the guides, or

$$V = \omega' r_1.$$

If the terminal element of the guide be tangent to that rim of the wheel, and the terminal element of the bucket be also tangent to that rim, and the wheel be frictionless, then

$$\alpha = 0, \quad \gamma_2 = 0, \quad \mu_1 = 0, \quad \mu_2 = 0,$$

and the velocity producing maximum efficiency will be, from Equation (16),

$$r_1\omega' = \sqrt{gH}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

or the velocity of the initial rim, if the wheel be frictionless, will be that due to half the head in the supply chamber.

If $r_2^2 = 2r_1^2$, then

$$r_2\omega' = \sqrt{2gH}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

or the velocity of the terminal rim will equal that due to the head. Substituting in (19) the values $\alpha = 0$, $\gamma_2 = 0$, $\mu_1 = 0$, $\mu_2 = 0$, $r_2^2 = 2r_1^2$, and it will reduce to

$$v_2 = \sqrt{2gH}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

as it should. That is, the quitting velocity backward in the bucket equals the velocity of that rim in the opposite direction.

The following table gives the values of quantities for the three classes of wheels:

TABLE I.

$\alpha = 0, \quad \gamma_2 = 0, \quad \mu_1 = 0, \quad \mu_2 = 0.$

Dimensions of Wheel.	Velocity of Inner Rim.	Velocity of Outer Rim.	Velocity of Exit from Guide V.	Velocity in Bucket. Initial v_1.	Velocity in Bucket. Terminal v_2.	Velocity of Exit. W.	Efficiency. E.
	ωr_1	ωr_2					
$r_1 = \sqrt{\frac{1}{2} r_2}$	$\sqrt{gH}$	$\sqrt{2gH}$	$\sqrt{gH}$	0.00	$\sqrt{2gH}$	0.00	1.000
$r_1 = r_2$	$\sqrt{gH}$	$\sqrt{gH}$	$\sqrt{gH}$	0.00	$\sqrt{gH}$	0.00	1.000
	ωr_2	ωr_1					
$r_1 = 1.4 r_2$	$0.714\sqrt{gH}$	$\sqrt{gH}$	$\sqrt{gH}$	0.00	$0.72\sqrt{gH}$	0.00	1.000

In the first case the inner rim is the initial one, in the third case the outer rim is initial, it being an inward flow wheel.

Since, in this case, the velocity of admission to the wheel in reference to the earth is that due to half the head in the supply chamber, and the velocity of exit is zero, it follows that the energy due to the velocity is all imparted to the wheel; and the energy due to the remaining half of the head is imparted to the wheel by pressure in the wheel. If the velocity of entrance to the wheel be that due to the head, or $V^2 = 2gH$, then will no energy be imparted to the wheel on account of pressure exerted by any part of the head H, but if $V^2 < 2gH$, then will some of the work be done by this pressure, w being zero. Or, briefly, in this case *the energy imparted to the wheel will be due one-half to velocity and one-half to pressure*; or in symbols,

$$U = \tfrac{1}{2} MV^2 - W.\tfrac{1}{2}H$$

$$= \tfrac{1}{2}\frac{W}{g}.gH - \tfrac{1}{2}WH = WH, \quad . \quad . \quad (28)$$

or, the entire potential energy of the water is expended in work upon the wheel.

Whenever $V^2 < 2gH$, there will be a pressure in the wheel at the initial element, and the equivalent head will be

$$H - \frac{V^2}{2g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

In practice, α cannot be zero and is made from 20° to 30°.

The value $r_1 = 1.4r_2$ makes the width of the crown for internal flow about the same as for $r_1 = \sqrt{\frac{1}{2}}r_2$ for outward flow, being approximately 0.3 of the external radius.

9. *Values of* μ_1 *and* μ_2.

The frictional resistances depend not only upon the construction of the wheel as to smoothness of the surfaces, sharpness of the angles, regularity of the curved parts, but also upon the manner it is run; for if run too fast, the initial elements of the wheel will cut across the stream of water, producing eddies and preventing the buckets from being filled, and if run too slow, eddies and whirls may be produced and thus the effective sections be reduced. These values cannot be definitely assigned beforehand, but Weisbach gives for good conditions,

$$\mu_1 = \mu_2 = 0.05 \text{ to } 0.10 \, . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

They are not necessarily equal, and μ_1 may be from 0.05 to 0.075, and μ_2 from 0.06 to 0.10, or values near these.

10. *Values of* γ_1.

It has already been shown that γ_1 must be less than $180° - \alpha$. If $\gamma_1 = 90°$, Equation (14) shows that the efficiency of the frictionless wheel will be independent of α. The effect of different values for γ_1 is best observed from numerical results as shown in the following table:

TABLE II.

Let $\alpha = 25°$, $\gamma_2 = 12°$, $\mu_1 = \mu_2 = 0.10$.

Initial Angle. γ_1. (1)	$r_1 = r_2\sqrt{\frac{1}{2}}$.			$r_1 = 1.4r_2$.		
	$\omega' r_2$. (2)	E. (3)	$\omega' r_1$. (4)	$\omega' r_2$. (5)	E. (6)	$\omega' r_1$. (7)
60°	$1.322\sqrt{gH}$	.812	$.934\sqrt{gH}$	$.780\sqrt{gH}$	.911	$1.092\sqrt{gH}$
90°	1.220 "	.827	.866 "	.689 "	.908	.964 "
120°	1.078 "	.838	.762 "	.576 "	.898	.806 "
150°	.518 "	.744	.366 "	.271 "	.752	.379 "

The values $\omega' r_2$ in columns (2) and (5) are velocities for the terminal rim, which in column (2) are for the exterior rim, but for column (5) it is the interior rim, while column (7) is for the exterior rim.

Columns (2) and (7) show that the velocity of the outer rim is less, for maximum effect, for the inflow than for the outflow, for a wheel of same outside diameter.

Column (3) shows that the efficiency, E, increases as the initial angle of the bucket, γ_1, increases up to 120°. An outflow wheel of these dimensions and with the assumed frictional resistances will have its greatest efficiency when the initial angle of the bucket, γ_1, is about 120° ; the velocity of the initial rim being about $0.76\sqrt{gH}$.

Column (6) shows that for the inflow wheel the efficiency continually decreases as γ_1 increases. If the head and quantity of water discharged be constant, the work would be proportional to the efficiency ; for, from Equation (14),

$$U = \delta QHE. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

For commercial considerations it may be necessary to sacrifice some efficiency to save on first cost, and to avoid making the wheel unwieldy.

The effect of γ_1 on the velocities and cross sections of the passages is shown in Table III.

TABLE III.

Let $\alpha = 25°$, $\gamma_2 = 12°$, $\mu_1 = \mu_2 = 0.10$, $Q = 1$.

Initial Angle. γ_1	$r_1 = r_2\sqrt{\frac{1}{2}}$.						$r_1 = 1.4\, r_2$.					
	$\frac{V}{\sqrt{gH}}$	$\frac{v_1}{\sqrt{gH}}$	$\frac{v_2}{\sqrt{gH}}$	$K \times \frac{}{\sqrt{gH}}$	$k_1 \times \frac{}{\sqrt{gH}}$	$k_2 \times \frac{}{\sqrt{gH}}$	$\frac{V}{\sqrt{gH}}$	$\frac{v_1}{\sqrt{gH}}$	$\frac{v_2}{\sqrt{gH}}$	$K \times \frac{}{\sqrt{gH}}$	$k_1 \times \frac{}{\sqrt{gH}}$	$k_2 \times \frac{}{\sqrt{gH}}$
60°	.820	.396	1.407	1.219	2.525	.691	.959	.463	.761	1.043	2.160	1.314
90°	.955	.403	1.317	1.047	2.481	.725	1.063	.449	.676	.940	2.227	1.479
120°	1.150	.560	1.153	.869	1.785	.874	1.217	.593	.605	.821	1.686	1.653
150°	2.100	1.775	.621	.476	.563	1.610	2.060	1.741	.296	.485	.574	3.378

From Equation (4) it appears that the pressure in the wheel at entrance, p_1, diminishes as the velocity of admission, V, increases, and, according to Equation (5), V depends upon γ_1 when α is fixed. Since the crowns are not fitted air tight nor water tight, it is desirable that p_1 should exceed the pressure of the atmosphere when the wheel runs in free air, or the pressure $p_2 + p_a$ when submerged, to prevent air or water from flowing in at the edge of the crown. It will be shown hereafter, in discussing the pressures in the wheel, that in order to secure a positive pressure at entrance into the wheel, we must have

$$-\tan\gamma_1 > \tan 2\alpha, \quad \ldots\ldots\ (32)$$

or, $$180° - \gamma_1 > 2\alpha,$$

or, $$\gamma_1 < 180° - 2\alpha.$$

If $$\alpha = 30,$$

then $$\gamma_1 < 120°.$$

To be on the safe side, the angle γ_1 may be 20 or 30 degrees less than $180° - 2\alpha$, giving

$$\gamma_1 = 180° - 2\alpha - 25 \text{ (say)}$$
$$= 155 - 2\alpha.$$

Then if $\alpha = 30°$, $\gamma_1 = 95°$. Some designers make γ_1, 90°; others more, and still others less, than that amount. Weisbach suggests that it be less, so that the bucket will be shorter and friction less. This reasoning appears to be correct for the in-

flow wheel, for the size and conditions shown in Table II., but not for the outflow wheel. In the Tremont turbines, described in the *Lowell Hydraulic Experiments*, this angle is 90°, the angle α, 20°, and γ_2, 10°, which proportions insured a positive pressure in the wheel. Fourneyron made $\gamma_1 = 90°$, and α from 30° to 33°, which values made the initial pressure in the wheel near zero.

In Table III. it appears that for $\gamma_1 = 150°$, $V = 2.1\sqrt{gH}$, which exceeds $\sqrt{2gH}$; that is, the velocity of exit from the supply chamber exceeds that due to the head, which condition must result from a negative pressure at entrance into the wheel. For zero pressure for the frictionless wheel, the above condition gives

$$\gamma_1 = 180° - 2\alpha,$$

which for $\alpha = 25°$, gives $\gamma_1 = 310°$, and for $\gamma_1 = 150°$, the pressure should be negative, and for 120° it should be positive. It appears that for the wheel *with friction*, for the values assumed in the table, that this pressure is also positive for $\gamma_1 = 120°$, and negative for 150°.

11. *Form of Bucket.*

The form of the bucket does not enter the analysis, and therefore its proper form cannot be determined analytically. Only the initial and terminal directions enter directly, and from these and the volume of the water flowing through the wheel, the area of the normal sections may be found from Equations (20).

But well-known physical facts determine that the changes of curvature and section must be gradual, and the general form regular, so that eddies and whirls shall not be formed. For the same reason the wheel must be run with the correct velocity to secure the best effect; for otherwise the effective angles α and γ_1 may be changed to values which cannot be determined beforehand, in which case the wheel cannot be correctly analyzed. In practice the buckets are made of two or three arcs of circles mutually tangential. Also, if the normal sections, K, k_1, k_2, of the buckets as constructed do not agree with those given by computation, the stream will, if possible, adjust itself to true conditions by the formation of eddies. If the terminal sections at the guides, or the initial section of the bucket, be too small, the action may be changed from a *pressure wheel* to one of *free*

deviation. So long as the pressure in the wheel exceeds the external pressure, the preceding analysis is applicable for the wheel running for best effect, observing that the sections K, k_1, k_2, may not be those of the wheel, but those which are computed from the velocities V, v_1, v_2.

12. *Value of* θ; or direction of the quitting water.

From Fig. 112 it may be found that

$$w \cos \theta = v_2 \cos \gamma_2 - \omega' r_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

and

$$w \sin \theta = v_2 \sin \gamma_2; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

$$\therefore \cot \theta = \cot \gamma_2 - \frac{\omega' r_2}{v_2 \sin \gamma_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

These formulas are for the velocity giving maximum efficiency. If the speed be assumed, ω in place of ω' becoming known, v_2 is given by Equation (19). It is apparent for such a case that θ may have a large range of values from $\theta = \gamma_2$, when the wheel is at rest, to θ exceeding 90° for high velocities. The following table gives some results; .

TABLE IV.

$\alpha = 25°$, $\gamma_2 = 12°$, $\mu_1 = \mu_2 = 0.10$.

γ_1	$r_1 = r_2 \sqrt{\frac{1}{2}}$.		$r_1 = 1.4 r_2$.	
	$\omega' r_2$	θ	$\omega' r_2$	θ
60°	$1.322 \sqrt{gH}$	80	$0.780 \sqrt{gH}$	102° 43′
90°	1.226 "	76	0.689 "	101° 17′
120°	1.078 "	72°	0.576 "	82° 52′
150°	0.518 "	55°	0.271 "	74° 51′

According to this table the water is thrown backward, or in the direction opposite to the motion of the wheel, for the outward flow wheel, and for the inflow it is thrown forward for γ_1 less than 90°, and backward for γ_1 greater than 120°.

In the *Tremont turbine* a device was used for determining the direction of the water leaving the wheel, and for the best effi-

ciency, 79¼%, the angle θ was about 120°. *Lowell Hydraulic Experiments*, p. 33.

The angle thus observed had a large range of values ranging from 50° to 140° for efficiencies only two or three per cent. less than 79¼%.

13. *Of the value of* ω.

So far as analysis indicates, the wheel may run at any speed; but in order that the stream shall flow smoothly from the supply chamber into the bucket—thus practically maintaining the angles α and γ_1, the relations in Equations (5) and (6) must be maintained, or

$$v_1 = \frac{\sin \alpha}{\sin \gamma_1} V, \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

and this requires that the velocity V shall be properly regulated, which can be done by regulating the head h_1 or the pressure p_1, or both h_1 and p_1, as shown by Equation (4). This however is not practical. In practice, the speed is regulated, and when the condition for maximum efficiency is established, the velocities V and v_1 are found from Equations (17) and (18).

Since γ_2, in practice, is small, and if the exit be radial, we have, for best effect,

$$v_2 = \omega' r_2, \text{ approximately}, \quad . \quad . \quad . \quad . \quad . \quad (37)$$

and, adopting this value, a more simple expression may be found for the velocity of the wheel. For Equation (19) gives

$$v_2 = r_2\omega' = \frac{\sqrt{gH}}{\sqrt{\frac{\cos \alpha \sin \gamma_1}{\sin (\alpha + \gamma_1)} \left(\frac{r_1}{r_2}\right)^2 + \frac{1}{2}\mu_1 \frac{\sin^2 \gamma_1}{\sin^2 (\alpha + \gamma_1)} \left(\frac{r_1}{r_2}\right)^2 + \frac{1}{2}\mu_2}}, \text{ approx.} \quad (38)$$

If $\mu_1 = \mu_2 = 0.10$, $r_2 \div r_1 = 1.40$, $\alpha = 25°$, $\gamma_1 = 90°$, the velocity of the *initial* rim for outward flow will be

$$\omega' r_1 = \frac{\sqrt{gH}}{\sqrt{1 + 0.159}} = 0.929 \sqrt{gH} \text{ (approx.)}.$$

The velocity due to the head would be

$$v_h = \sqrt{2gH} = 1.414 \sqrt{gH};$$

hence, the velocity of the initial rim should be about

$$\frac{0.929\sqrt{gH}}{1.414\sqrt{gH}} = 0.659 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad . \quad (39)$$

of the velocity due to the head.

The more accurate value for these proportions, as given in Table II., is

$$\frac{0.866}{1.414} = 0.614.$$

For an inflow wheel for the case in which $r_1^2 = 2r_2^2$, and the other dimensions as given above, this becomes

$$\frac{0.954}{1.414} = 0.674 \text{ (approx.)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

of the velocity due to the head.

The more accurate value given by Table II. is

$$\frac{0.964}{1.414} = 0.682.$$

The highest efficiency of the Tremont turbine, found experimentally, was 0.79375, and the corresponding velocity, 0.62645 of the velocity due to the head, and for all velocities above and below this value the efficiency was less. It will be seen that these results agree quite nearly with those given above, but it should be noticed that the dimensions of the wheel are slightly different. In the Tremont wheel $\alpha = 20°$ instead of 25°, and $\gamma_2 = 10°$ instead of 12°. These would make the theoretical efficiency and velocity of the wheel somewhat greater. This indicates that the frictional losses in the Tremont system exceeded those here assumed; a part of which may have existed in the supply chamber, which we have not considered. Experiment showed that the velocity might be considerably larger or smaller than this amount without diminishing the efficiency very much.

In the Tremont turbine it was found that if the velocity of the initial (or interior) rim was not less than 44% nor more than 75% of that due to the fall, the efficiency was 75% or more. (*Exp.*, p. 44.) This wheel was allowed to run freely without any brake

except its own friction, and the velocity of the initial rim was observed to be $1.335\ \sqrt{2gH}$, half of which is

$$0.6675\ \sqrt{2gH}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

"which is not far from the velocity giving maximum effect; that is to say, *when the gate is fully raised the coefficient of effect is a maximum when the wheel is moving with about half its maximum velocity.*" (*Exp.*, p. 37.)

M. Poncelet computed the theoretical useful effect of a certain turbine of which M. Morin had determined the value by experiment. The following are the results (*Comptes Rendus*, 1838, *Juillet*):

TABLE V.

Velocity of initial rim or $\frac{r_1\omega'}{\sqrt{2gH}} =$	Number of turns of the wheel per minute.	Ratio of useful to theoretical effect.	Means of values by experiment.
0.0	0.00	0.000	.....
0.2	33.80	0.664	.....
0.4	47.87	0.773	0.700
0.6	58.61	0.807	0.705
0.7	62.81	0.810	0.700
0.8	67.67	0.806	0.675
1.0	75.76	0.786	0.610
1.2	82.88	0.753	0.490
1.4	89.52	0.712	0.360
1.6	95.70	0.664	0.280
1.8	101.51	0.612	0.203
2.0	107.00	0.546	0.050
3.72	145.00	0.000	.....

Poncelet states that he took no account of passive resistances, and hence his results should be larger than those of experiment, as they are; but here both theory and experiment give the maximum efficiency for a velocity of about 0.6 that due to the head, and the efficiency is but little less for velocities perceptibly greater and less than that for the best effect. For velocities considerably greater and less, theoretical results are much larger than those found by experiment, for reasons already given, the chief of which is due to eddies changing the effective angles of the mechanism.

14. *Pressure in the Wheel.*

Dropping the subscript $_2$ from r, v, p, in Equation (9), the resulting value of p will give the pressure per unit at any point

of the bucket, providing that μ_2 be considered constant. Changing r to ρ, Equation (9) thus gives

$$p = \left[v_1^2 - (1 + \mu_2)\, v^2 + \omega^2 (\rho^2 - r_1^2) \right] \frac{\delta}{2g} + p_1. \quad . \quad (42)$$

The velocity v may be found from Equation (19) by dropping the subscripts 2 from v and r, and the corresponding value of k in Equation (20) becomes known. Equations (20) and (6) give

$$v = v_1 \frac{k_1}{k} = \frac{k_1}{k} \cdot \frac{\sin \alpha}{\sin (\alpha + \gamma_1)} \cdot \omega r_1. \quad . \quad . \quad . \quad (43)$$

From (4) and (5),

$$p_1 = \delta h_1 + p_a - \delta \frac{1 + \mu_1}{2g} \cdot \frac{\sin^2 \gamma_1}{\sin^2 (\alpha + \gamma_1)} \omega^2 r_1^2. \quad . \quad (44)$$

These reduce Equation (42) to

$$\frac{gp}{\delta} = \frac{gp_a}{\delta} + gh_1 + \tfrac{1}{2} \omega^2 \rho^2 - \tfrac{1}{2} \omega^2 r_1^2$$

$$- \frac{1}{2} \left[(1 + \mu_1) \sin^2 \gamma_1 + [k_1^2 (1 + \mu_2) - k^2] \frac{\sin^2 \alpha}{k^2} \right] \frac{\omega^2 r_1^2}{\sin^2 (\alpha + \gamma_1)}. \quad (45)$$

The back or concave side of the bucket will be subjected to a pressure which may be considered in two parts: one due to the deflection of the stream passing through it, the other to a pressure which is the same as that against the crown, and is uniform throughout the cross section of the bucket, due to the pressure of a part (or all) of the head in the supply chamber. It is the latter pressure which is given by the value of p in Equation (45). The construction of the wheel being known, the pressure p may be found at any point of the wheel for any assumed practical velocity; although, for reasons previously given, it will be of practical value only when running near the velocity for maximum efficiency. There are two cases:

1. That in which the discharge is into free air;
2. That in which the wheel is submerged. (The remainder of this paragraph is an abstract from Woodbridge's paper.)

In the first case, if the pressure is uniform, the case is called that of "free deviation," in which the entire pressure upon the forward side of the bucket is due to the deviation of the water from a right line, and will be considered further on.

If Equation (45) shows a continually decreasing pressure from

the initial element to that of exit, or if the minimum pressure exceeds p_a, the preceding analysis is applicable. But if it shows a point of minimum pressure less than p_a, it will be in a condition of unstable equilibrium, in which the slightest inequality would cause air to rush in and restore the pressure to that of the atmosphere; so that the pressure in the wheel and the flow would be changed. The point of minimum pressure may be found by plotting results found from Equation (45), substituting values for ρ taken from measurements of the wheel, and k from computation. From the entrance of the wheel up to the point of minimum pressure the preceding analysis applies; and the remainder of the wheel must be analyzed for "free deviation" and the two results added.

In the second case the equations will apply, since air cannot enter, provided that γ does not become negative, to realize which requires a tensile stress of the water. This is impossible, and eddies would be formed; and the effect of these on the velocity and pressure cannot be computed. Such a case cannot be analyzed.

15.* *To find the pressure at the entrance to the bucket* when running at best effect. In (45) let $\rho = r_1$, $k = k_1$ and $p = p_1$. To simplify still more, let the wheel be frictionless, or $\mu_1 = \mu_2 = 0$, and find from Equation (38) the approximate value,

$$r_1^2\omega'^2 = \frac{\sin(\alpha + \gamma_1)_1}{\cos\alpha \sin\gamma} gH, \quad . \quad . \quad . \quad . \quad . \quad (46)$$

also $h_1 = H + h_2$, and (45) becomes

$$p_1 = \delta H + \delta h_2 + p_a - \frac{\delta \sin\gamma_1}{2\cos\alpha \sin(\alpha + \gamma_1)} H. \quad . \quad . \quad (47)$$

If the wheel is not submerged $h_2 = 0$, and let the pressure p_1 equal that of the atmosphere, or p_a, then

$$0 = 1 - \frac{\sin\gamma_1}{2\cos\alpha \sin(\alpha + \gamma_1)}. \quad . \quad . \quad . \quad (48)$$

If the wheel be submerged, let $p_1 = \delta h + p_a$, and the equation reduces to that of the preceding.

Equation (48) gives

$$\tan 2\alpha = -\tan\gamma_1,$$

or,

$$2\alpha = 180^\circ - \gamma_1; \quad . \quad . \quad . \quad . \quad . \quad (49)$$

for which value the pressure at the entrance to the wheel will equal that just outside.

If $$2\alpha > 180^\circ - \gamma_1, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

the pressure within will be less than that without; but if

$$2\alpha < 180^\circ - \gamma_1, \quad . \quad . \quad . \quad . \quad . \quad . \quad (51)$$

the pressure within will exceed that without—a condition which is considered desirable. If frictional resistances be considered, the value of $r_1\omega'$ from Equation (38) will be less than that given by (46), and hence the last term of Equation (47) will be less unless α be greater than the value given by Equation (51); hence with frictional resistances the terminal angle of the guide blade may exceed somewhat $90^\circ - \frac{1}{2}\gamma_1$; therefore, if the value of α be found for a frictionless wheel it will be a safe value when there is friction. If $\gamma_1 = 90^\circ$ and $\alpha = 90^\circ - \frac{1}{2}\gamma_1 = 45^\circ$, then (47) gives

$$p_1 = \delta H + \delta h_2 + p_a - \delta H = \delta h_2 + p_a, \quad . \quad . \quad . \quad (52)$$

as it should. If $\gamma_1 = 90^\circ$ and $\alpha = 30^\circ$, then

$$p_1 = \delta H + \delta h_2 + p_a - 0.\tfrac{2}{3}\delta H,$$

or, $$p_1 > \delta h_2 - p_a + 0.33\delta H. \quad . \quad . \quad . \quad . \quad . \quad . \quad (53)$$

The angle α should not be so large or γ_1 so small as to produce excessive pressure at the entrance to the wheel.

16. *Number of Buckets.*

The analysis given above is true for a wheel with a single bucket, provided the supply is constantly open to the bucket and closed by the remainder of the wheel. But for practical considerations the wheel should be full of buckets, although the number cannot be determined by analysis. Successful wheels have been made in which the distance between the buckets was as small as 0.75 of an inch, and others as much as 2.75 inches. (*Lowell Hyd. Exp.*, p. 47.) Turbines at the Centennial Exposition had buckets from $1\frac{1}{2}$ inches to 9 inches from centre to centre. If too large they will not work properly. Neither should they be too deep Horizontal partitions are sometimes introduced. These secure more efficient working in case the gates are only partly opened. The form and number of buckets for commercial purposes are chiefly the result of experience.

17. *Ratio of Radii.*

Theory does not limit the dimensions of the wheel. In practice,

$$\left.\begin{array}{l}\text{for outward flow, } r_2 \div r_1 \text{ is from 1.25 to 1.50}\\ \text{for inward flow, } r_2 \div r_1 \text{ is from 0.66 to 0.80}\end{array}\right\} \quad . \quad . \quad (54)$$

It appears from Table II. that the inflow wheel has a higher efficiency than the outward flow wheel (columns 6 and 3), and these wheels have about the same outside and inside diameters. The inflow wheel also runs somewhat slower for best effect. The centrifugal force in the outward flow wheel tends to force the water outward faster than it would otherwise flow; while in the inward flow wheel it has the contrary effect, acting to reduce the velocity in the buckets.

It also appears that the efficiency of the outward flow wheel increases slightly as the width of the crown is less, and the velocity for maximum efficiency is slower; while for the inflow wheel the efficiency slightly increases for increased width of crown and the velocity of the outer rim at the same time also increases.

18. *Efficiency*, E.

The method of determining the theoretical value of the maximum efficiency has already been given, and application made to some ideal cases in Table II. For the outward flow wheel nearly 86% was found, and for the inflow over 91%. These, however, do not include losses by impact, nor losses in the supply chamber. The exact value of the efficiency for a particular wheel must be found by experiment; but by assuming minimum values for the several losses, a limit to the maximum efficiency may be fixed. Thus, if the actual velocity be 0.98 of the theoretical, the energy lost will be $(1 - 0.98^2)$ or 4%.

Friction along the buckets and bends, say	3%.
Lost by water escaping at joint, say	1%.
Energy lost by impact, say	2%.
Energy lost in supply chamber	2%.
Energy lost in the escaping water	2%.
Total	14%.
Leaving	86%

available for work.

It seems hardly possible for the effective efficiency to equal, much less exceed, 86%, and all claims of 90 or more % for these motors may be questioned. A turbine yielding from 75 to 80% is extremely good. Experiments with higher efficiencies have been reported, especially when the test was for a few minutes only. It is reported that the purchasers of a certain Boyden turbine were willing to pay for 90% efficiency. The celebrated Tremont turbine, made after the pattern of the Boyden, gave 79½% without the "diffuser," which might have added some 2%. The Tremont turbine was a "commercial" wheel: the Boyden wheel had polished buckets, and was otherwise made exquisitely fine. A Jonval turbine (parallel flow) was reported as yielding 0.75 to 0.90, but Morin suggested corrections reducing it to 0.63 to 0.71. (Weisbach, *Mech. of Eng.*, vol. ii. p. 501.) Weisbach gives the results of many experiments, in which the efficiency ranged from 50 to 84%. See pages 470, 500–507. (See also *Jour. Frank. Inst.*, 1843, for efficiencies from 64 to 75%.) Numerous experiments give E = 0.60 to 0.65. The efficiency, considering only the energy imparted to the wheel, will exceed by several per cent. the efficiency of the wheel, for the latter will include the friction of the support, and leakage at the joint between the sluice and wheel, which are not included in the former; also as a plant the resistances and losses in the supply chamber are to be still further deducted.

19. *The Crowns.*

The crowns may be plane annular disks, or conical, or curved. If the partitions forming the buckets be so thin that they may be discarded, the law of radial flow will be determined by the form of the crowns. If the crowns be plane, the radial flow (or radial component) will diminish, for the outward flow wheel, as the distance from the axis increases—the buckets being full—for the annular space will be greater.

20. *Designing.*

The dimensions of a wheel must be determined for a definite velocity. Thus far it has been assumed that the angles α, γ_1, etc., are given, and the normal sections of the stream thus deduced. We will now assume that all the dimensions of the buckets are known, and the angle α and the section K are to be

determined. The velocities v_1 and v_2 must now be found independently of α. From Fig. 112 we have

$$V^2 = v_1^2 + \omega^2 r_1^2 - 2v_1\omega r_1 \cos \gamma_1, \quad . \quad . \quad . \quad . \quad . \quad (55)$$

which, combined with Equations (4), (9), (10), $v_1 k_1 = v_2 k_2$, as in (20), and $H = h_1 - h_2$, will give

$$v_2 = \frac{k_1}{k_2} v_1 = \frac{(1 + \mu_1) k_1 k_2 \omega r_1 \cos \gamma_1}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2}$$

$$+ \sqrt{\frac{2gH + [r_2^2 - (2 + \mu_1) r_1^2] \omega^2}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2} k_1^2 + \left[\frac{(1 + \mu_1) k_1 k_2 \omega r_1 \cos \gamma_1}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2}\right]^2}$$

$$= A\omega + \sqrt{2gHB + C^2\omega^2}; \quad . \quad . \quad . \quad . \quad . \quad (56)$$

where

$$A = \frac{(1 + \mu_1) k_1 k_2 r_1 \cos \gamma_1}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2}, \quad . \quad . \quad . \quad . \quad . \quad (56a)$$

$$B = \frac{k_1^2}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2} \quad . \quad . \quad . \quad . \quad . \quad (56b)$$

$$C^2 = \frac{r_2^2 - (2 + \mu_1) r_1^2}{(1 + \mu_2) k_1^2 + \mu_1 k_2^2} k_1^2 + A^2 \quad . \quad . \quad . \quad (56c)$$

$$v_1 = \frac{k_2}{k_1} v_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

To find expressions for the work and efficiency in terms of the angular velocity, eliminate w, V, v_2, v_1, between Equations (12), (13), (11), (56), (55), (57), and making

$$\left.\begin{aligned} a &= 1 + \mu_2 + \mu_1 \frac{k_2^2}{k_1^2}, \\ b &= r_2 \cos \gamma_2 + \mu_1 \frac{k_2}{k_1} r_1 \cos \gamma_1, \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (57a)$$

we find

$$E = \frac{U}{\delta Q H} = \frac{1}{gH}\Big[gH - agHB - [\tfrac{1}{2}a(A^2 + C^2) - bA + \tfrac{1}{2}r_2^2 + \tfrac{1}{2}\mu_1 r_1^2]\,\omega^2$$

$$+ b - aA\omega \sqrt{2gHB + C^2\omega^2}\Big] \quad . \quad . \quad . \quad . \quad . \quad (58)$$

Let

$$\left.\begin{aligned} D &= gH(1 - aB). \\ F^2 &= \tfrac{1}{2}a(A^2 + C^2) - bA + \tfrac{1}{2}r_2^2 + \tfrac{1}{2}\mu_1 r_1^2. \\ G &= b - aA. \end{aligned}\right\} \quad . \quad . \quad (58a)$$

Then,

$$E = \frac{1}{gH}[D - F^2\omega^2 + G\omega\sqrt{2gHB + C^2\omega^2} \quad . \quad . \quad (59)$$

For a maximum $dE/d\omega = 0$, giving

$$\omega^2 = gHB\frac{F^2 - \sqrt{F^4 - C^2G^2}}{C^2\sqrt{F^4 - C^2G^2}} \quad . \quad . \quad . \quad . \quad . \quad (60)$$

Call this value of ω, ω'. This is of the same form as Equation (16). This value substituted in Equation (59) gives, observing that $aB = 1$, and hence $D = 0$,

$$E_{max} = (F^2 - \sqrt{F^4 - C^2G^2})\frac{B}{C^2} \quad . \quad . \quad . \quad (61)$$

Equation (60) becomes

$$\omega^2 = \frac{E_{max}}{\sqrt{F^4 - C^2G^2}}gH, \quad . \quad . \quad . \quad . \quad . \quad (61a)$$

which is more convenient for computing the value of ω.

For the frictionless wheel $a = 1$ and $B = 1$.

The terminable angle α of the guide blade may now be determined to secure smooth running of the stream. Fig. 112 gives

$$V\cos\alpha = \omega r_1 - v_1\cos\gamma_1,$$

which gives

$$\cos\alpha = \frac{\omega r_1 - v_1\cos\gamma_1}{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad (62)$$

Eliminating r_1 by means of Equations (57) and (56) gives $\cos\alpha$ in terms of the six constants r_1, r_2, γ_1, γ_2, k_1 and k_2, which are fixed and known from the dimensions of the wheel, and of the velocity ω of the wheel. Since the wheel may run at different velocities the angle α must vary, and if this angle be too large, this will be done in practice by the piling of the water in the passages in the supply chamber; and, if too small, in the buckets. Each turbine, however, should be designed to run at the speed giving maximum efficiency, and its angles and dimensions should satisfy Equations (60) and (62).

From Equation (9),

$$2g\frac{p_1}{\delta} = (1 + \mu_2)\,v_2^2 - v_1^2 - \omega^2(r_2^2 - r_1^2) + 2g\frac{p_a + \delta h_2}{\delta}, \quad . \quad (63)$$

in which, if v_2 and v_1 be substituted from above, p_1 becomes known.

For the wheel in which the crowns are plane disks, the depth will be uniform and the normal sections of the buckets will vary as the normal distance between the traces of the buckets on the plane of the disks. Let eg and hh (Fig. 113) be the plan of the walls of a bucket; then, neglecting the thickness of those walls, eh will be to gh as r_1 to r_2 for the outflow wheel, and as r_2 to r_1 for the inflow; and the sections at gi and db will be as gh sin γ_2 to eh sin γ_1, the distance gh being practically small. Then

$$\frac{k_1}{k_2} = \frac{r_1 \sin \gamma_1}{r_2 \sin \gamma_2}. \quad \ldots \ldots \ldots \quad (64)$$

By means of these equations the following tables have been formed:

TABLE VI.

OUTWARD FLOW TURBINE. $r_1 = r_2\sqrt{\tfrac{1}{2}}$. $\mu_1 = \mu_2 = 0.10$. $\gamma_2 = 12°$. Parallel crowns. $k_1 r_1 = k_2 r_2 = K V = Q = 1$.

Initial angle. γ_1	Efficiency E. Eq. (61).	Vel. outer rim. $r_2\omega'$ Eq. (60).	Vel. inner rim. $r_1\omega' = \sqrt{\tfrac{1}{2}}\, r_2\omega'$	Relative velocity of exit. v_2 Eq. (56).	Relative velocity of entrance. v_1 Eq. (57).	Velocity of exit from supply chamber. V Eq. (55).	Terminal angle of guide. α Eq. (62).	Direction of quitting water. θ Eq. (35).	Head equivalent of energy in quitting water. $\frac{w^2}{2g}$	$k_2\sqrt{gH}$	$k_1\sqrt{gH}$	$K\sqrt{gH}$
1	2	3	4	5	6	7	8	9	10	11	12	13
60°	0.804	$1.374\sqrt{gH}$ $0.972\sqrt{2gH}$	$0.972\sqrt{gH}$ $0.687\sqrt{2gH}$	$1.483\sqrt{gH}$ $1.048\sqrt{2gH}$	$0.503\sqrt{gH}$ $0.356\sqrt{2gH}$	$0.842\sqrt{gH}$ $0.595\sqrt{2gH}$	31° 17′	76°	$0.051H$	0.67	1.988	1.187
90°	0.828	$1.236\sqrt{gH}$ $0.874\sqrt{2gH}$	$0.874\sqrt{gH}$ $0.619\sqrt{2gH}$	$1.317\sqrt{gH}$ $0.931\sqrt{2gH}$	$0.387\sqrt{gH}$ $0.274\sqrt{2gH}$	$0.956\sqrt{gH}$ $0.676\sqrt{2gH}$	23° 56′	79°	$0.039H$	0.76	2.584	1.046
120°	0.841	$1.129\sqrt{gH}$ $0.798\sqrt{2gH}$	$0.798\sqrt{gH}$ $0.565\sqrt{2gH}$	$1.192\sqrt{gH}$ $0.843\sqrt{2gH}$	$0.405\sqrt{gH}$ $0.286\sqrt{2gH}$	$1.060\sqrt{gH}$ $0.749\sqrt{2gH}$	19° 5′	82°	$0.031H$	0.84	2.444	0.943
150°	0.921	$1.005\sqrt{gH}$ $0.709\sqrt{2gH}$	$0.709\sqrt{gH}$ $0.501\sqrt{2gH}$	$0.999\sqrt{gH}$ $0.707\sqrt{2gH}$	$0.587\sqrt{gH}$ $0.416\sqrt{2gH}$	$1.252\sqrt{gH}$ $0.886\sqrt{2gH}$	13° 31′	97°	$0.022H$	1.00	1.703	0.799

TABLE VII.

INWARD FLOW TURBINE. $r_1 = \sqrt{2}\, r_2$. $\mu_1 = \mu_2 = 0.10$. $\gamma_2 = 12°$. Parallel crowns. $k_1 r_1 = k_2 r_2 = K V = Q = 1$.

γ_1	E.	Velocity outer rim. $r_1\omega'$	Velocity inner rim. $r_2\omega'$	v_2	v_1	V	α	θ	$\frac{w^2}{2g}$	$k_2\sqrt{gH}$	$k_1\sqrt{gH}$	$K\sqrt{gH}$
1	2	3	4	5	6	7	8	9	10	11	12	13
60°	0.920	$1.003\sqrt{gH}$ $0.709\sqrt{2gH}$	$0.709\sqrt{gH}$ $0.501\sqrt{2gH}$	$0.673\sqrt{gH}$ $0.476\sqrt{2gH}$	$0.115\sqrt{gH}$ $0.089\sqrt{2gH}$	$0.951\sqrt{gH}$ $0.672\sqrt{2gH}$	7° 0′	110°	$0.010H$	1.48	8.65	1.05
90°	0.920	$0.973\sqrt{gH}$ $0.688\sqrt{2gH}$	$0.688\sqrt{gH}$ $0.487\sqrt{2gH}$	$0.664\sqrt{gH}$ $0.470\sqrt{2gH}$	$0.098\sqrt{gH}$ $0.069\sqrt{2gH}$	$0.977\sqrt{gH}$ $0.691\sqrt{2gH}$	5° 28′	106°	$0.010H$	1.50	10.20	1.02
120°	0.919	$0.945\sqrt{gH}$ $0.668\sqrt{2gH}$	$0.668\sqrt{gH}$ $0.473\sqrt{2gH}$	$0.645\sqrt{gH}$ $0.456\sqrt{2gH}$	$0.109\sqrt{gH}$ $0.077\sqrt{2gH}$	$1.004\sqrt{gH}$ $0.709\sqrt{2gH}$	4° 46′	105°	$0.010H$	1.55	9.17	0.99
150°	0.918	$0.897\sqrt{gH}$ $0.634\sqrt{2gH}$	$0.634\sqrt{gH}$ $0.448\sqrt{2gH}$	$0.607\sqrt{gH}$ $0.429\sqrt{2gH}$	$0.178\sqrt{gH}$ $0.126\sqrt{2gH}$	$1.053\sqrt{gH}$ $0.743\sqrt{2gH}$	3° 08′	104°	$0.009H$	1.65	5.05	0.95

21. *Path of the Water.*

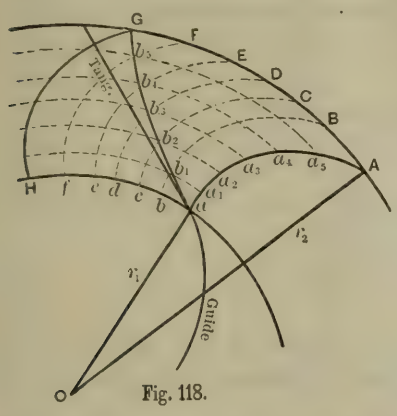


Fig. 118.

Let aB be the position of the bucket when the water enters at a. The bucket being drawn in position to a scale, divide it into any number of parts—equal or unequal—aa_1, $a_1\ a_2$, etc., and find the time required for it to go from a to a. The distance being small, assume that the velocity is uniform from a to a_1, and equal to v, which will be given by Equation (62) by dropping all the subscripts $_2$ and changing r to ρ, thus,

$$v = \frac{(1+\mu_1)\,k_1\,k\omega r_1 \cos\gamma_1}{(1+\mu_2)\,k_1^2+\mu_1\,k^2} + \sqrt{\frac{2gH+\omega^2\left[\rho^2-(2+\mu_1)\,r_1^2\right]}{(1+\mu_2)\,k_1^2+\mu_1\,k^2}\,k_1^2+\left[\frac{(1+\mu_1)\,k_1\,k\omega r_1\cos\gamma_1}{(1+\mu_2)\,k_1^2+\mu_1\,k_2^2}\right]^2} \quad (64a)$$

Then will the time t be

$$t = \frac{aa_1}{v}. \quad (65)$$

During this time the rim will have gone from a to b a distance

$$ab = r_1\,\omega t. \quad (66)$$

If the bucket bB be drawn through b, and the arc a_1b_1 through a_1, their intersection b_1 will be the position of the particle at the end of the time t. In a similar manner, the successive points b_2, b_3, etc., may be found, through which a continuous curve may be drawn representing the path of the stream.

The line tangent to the guide at its terminal element will indicate the direction of the water at entrance of the wheel, and if the water drives the wheel, the *path* should be entirely outside this line and convex toward it.

22. *Other Losses.*

If the turbine revolves in air, at least half the depth of the wheel is to be deducted from the head H.

If the circular opening between the wheel and sluice be $\frac{1}{16}$ of an inch, or $\frac{1}{192}$ of a foot, and the coefficient of discharge be 0.7, the discharge will be

$$0.7 \times \frac{1}{192} \times 2\pi r_1 \times \sqrt{\frac{2gp_1}{\delta}} = q, \quad . \quad . \quad . \quad . \quad (67)$$

p_1 being determined from Equation (63). The corresponding loss of work will be

$$62.2q\,(H - \tfrac{1}{2}y). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

The work lost by friction, if the radius of the axle be r_3, the weight of the loaded wheel, W_3, and coefficient of friction μ_3, will be nearly

$$\frac{2}{3}\mu_3 W_3 \frac{r_3}{\omega}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69)$$

The work to be done by the water must be the effective U plus the work due to the losses. Call this U_1. Compute the work done by the water in the wheel of assumed dimensions, and let it be U_2; then will the required depth be

$$y_2 = \frac{U_1}{U_2} y. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (70)$$

SPECIAL WHEELS.

23. *Fourneyron Turbine.*

All wheels having guide blades are of the Fourneyron type, although the wheels made by him were outward flow. The preceding analysis is a general solution of this turbine.

24. *Francis and Thomson's vortex wheels* are inward flow wheels with guide blades. The preceding analysis is also applicable to these wheels.

25. *The Jonval Turbine* is a parallel flow wheel with guide blades, to which the preceding analysis is applicable by making $r_1 = r_2$.

(For the details of these and many other forms, see *Hydraulic Motors* by Weisbach.)

26. *Rankine Wheel.*

This is a wheel of the Fourneyron type, but Rankine having made certain modifications in its assumed construction, it is indicated by his own name.

In this wheel the crowns are so made that the *radial* velocity of the water in passing through the wheel will be uniform

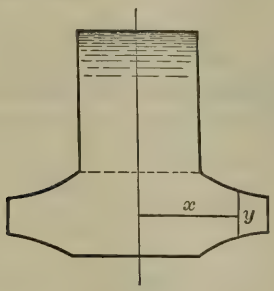


FIG. 119.

(Fig. 119). If x be the abscissa from the axis of the wheel to any point of the crown, and y the distance between the crowns at that point, v_r the radial component of the velocity, then

$$y \cdot 2\pi x \; v_r = Q,$$

or,

$$yx = a \text{ constant}, \quad . \quad . \quad . \quad . \quad (71)$$

which is the equation to an hyperbola referred to its asymptotes. This determines the form of the crowns. If the wheel were inward flow, the depth would be greatest at the quitting rim.

In this wheel the initial element of the bucket is radial, or $\gamma_1 = 90°$; and Rankine *assumed* that the velocity for best effect must be such that the water will quit the wheel radially, or $\theta = 90°$. These conditions given, from Fig. 112 and Equations (5), (6), (34), for a *frictionless* wheel,

$$\omega r_1 = V \cos \alpha. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

$$\omega r_2 = v_2 \cos \gamma_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (73)$$

$$v_1 = w = V \sin \alpha = \omega r_1 \tan \alpha = \omega r_2 \tan \gamma_2 = v_2 \sin \gamma_2; \quad . \quad (74)$$

$$\therefore \tan \alpha = \frac{r_2}{r_1} \tan \gamma_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (75)$$

which determines the proper angle of the guide blade when the value of γ_2 has been assigned. If $\gamma_2 = 15°$, $r_2 = 1\frac{1}{4} r_1$, then $\alpha = 18\frac{1}{2}°$; and if $\gamma_2 = 20°$, $r_2 = 1.3$, then $\alpha = 24°$ nearly. Equations (19), (73), and (75) give

$$\omega r_1 = \sqrt{\frac{2gH}{2 + \tan^2 \alpha}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (76)$$

which establishes the velocity of the initial rim of the wheel.

The work in the frictionless wheel will be the theoretical work the water could do, less the energy in the water quitting the wheel, or

$$U = WH - \tfrac{1}{2} \frac{W}{g} w^2$$

[Eq. (74)] $$= WH - \tfrac{1}{2} \frac{W}{g} r_1^2 \omega^2 \tan^2 \alpha. \quad . \quad . \quad . \quad (77)$$

[Eq. (76)] $$= \frac{WH}{1 + \frac{1}{2} \tan^2 \alpha}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (78)$$

The efficiency will be

$$E = \frac{U}{WH} = \frac{1}{1 + \frac{1}{2} \tan^2 \alpha}. \quad . \quad . \quad . \quad . \quad . \quad (79)$$

27. The following is to show that Rankine's assumption of velocity for best efficiency is not quite correct. Substituting $\gamma_1 = 90°$, $\mu_1 = \mu_2 = 0$, $r_1 = nr_2$, $k_1 = k_2$, in Equation (60), one finds

$$\omega^2 r_2^2 = \frac{gH}{1 - 2n^2} \left[\frac{1 - n^2 - \sqrt{(1 - n^2)^2 - \cos^2 \gamma_2 (1 - 2n^2)}}{\sqrt{(1 - n^2)^2 - \cos^2 \gamma_2 (1 - 2n^2)}} \right]. \quad (80)$$

and these in Equation (56) will give

$$v_2 \cos \gamma_2 = \sqrt{gH \cos^2 \gamma_2 \left[\frac{1 - n^2 + \sqrt{(1 - n^2)^2 - \cos^2 \gamma_2 (1 - 2n^2)}}{\sqrt{(1 - n^2)^2 - \cos^2 \gamma_2 (1 - 2n^2)}} \right]}$$

$$= \omega r_2 \left[1 - n^2 + \sqrt{(1 - n^2)^2 - \cos^2 \gamma_2 (1 - 2n^2)} \right]. \quad . \quad (81)$$

This does not give

$$v_2 \cos \gamma_2 = \omega r$$

as in Equation (73), except when $n^2 = \frac{1}{2}$ (or $2r_1^2 = r_2^2$); and hence the direction of the water at exit will not be radial, as Rankine assumed, except for this case. In practice, outflow wheels are constructed almost exactly with this proportion, $n^2 = \frac{1}{2}$, and hence the analysis from Equations (72) to (79) is sufficiently exact for the frictionless outflow wheel; and, as seen above, the hypothesis greatly simplifies the analysis. For the inflow wheel, the direction of quitting for best effect will depart perceptibly from radial.

The condition for best efficiency of the frictionless wheel requires that the velocity of leaving the wheel should be a minimum; and this may be realized, in some cases, when its direction is oblique to the radius.

Thus, let AC be radial when AB is the velocity relative to

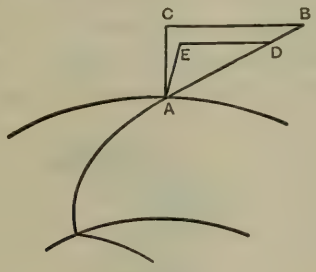


FIG. 120.

the bucket, and BC the velocity of the rim; then it may be, in some cases, that when AD is the relative velocity of exit, AE, the velocity of exit relative to the earth, will be less than AC, as shown in Fig. 120.

.28. *The path of the water* is easily constructed for this wheel. Since the radial velocity is uniform, the time of flowing through the wheel will be

$$t = \frac{r_2 - r_1}{v_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (82)$$

during which time the initial rim aH, Fig. 118, will have traveled

$$ab = \omega r_1 t \text{ feet} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (83)$$

Divide $r_2 - r_1$ into equal parts by concentric arcs, and the space aH into the same number of equal parts, and through the points of division a, b, c, d, trace the buckets; then will aG,

drawn through the proper intersections of the arcs and buckets, be the required path.

29. *Centrifugal Pump.*

If a turbine be forced to rotate backwards, it becomes a centrifugal pump. In Fig. 121, let AB be the velocity of the quitting water relative to the bucket, BD the velocity of the rim of

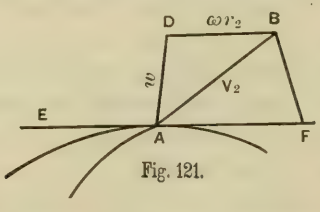


Fig. 121.

the wheel when it operates as a motor; then will AD be the quitting velocity relative to the earth. But if AF be the velocity of the rim when acting as a pump, then will BF be the velocity of the entering water relative to the earth. The speed

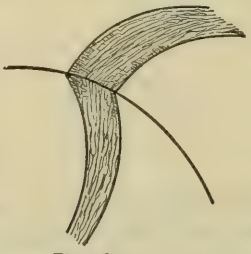


Fig. 117.

must be such as to produce the required pressure at the foot of the shaft.

30. *Wheel of Free Deviation.*

In this wheel the water in the buckets has a free surface, or, in other words, is subjected only to the pressure of the atmosphere. For this case

$$p_2 = p_1 = p_a;\ h_1 = H, \text{ and } h_2 = 0,$$

and Equation (4) gives

$$(1 + \mu_1)\ V^2 = 2gH, \quad . \quad . \quad . \quad . \quad . \quad . \quad (84)$$

which will be the velocity of discharge from the supply chamber

into the wheel; it is the velocity due to the head in the supply chamber when frictional resistance is included.

The triangle ABC, Fig. 112, gives

$$v_1^2 = V^2 + \omega^2 r_1^2 - 2\,V\omega r_1 \cos \alpha, \quad . \quad . \quad . \quad . \quad (85)$$

which substituted in Equation (5) gives

$$(2 + \mu_2)\, v_2^2 = V^2 + \omega^2 r_2^2 - 2V.\ \omega r_1 \cos \alpha. \quad . \quad . \quad (86)$$

31. *To find the velocity at any point of the bucket relative to the bucket*, drop the subscript $_2$ from Equation (86), giving

$$(1 + \mu_2)\, v^2 = 2gH + \omega^2 r_2^2 - 2\sqrt{2gH}.\ \omega r_1 \cos \alpha. \quad . \quad (87)$$

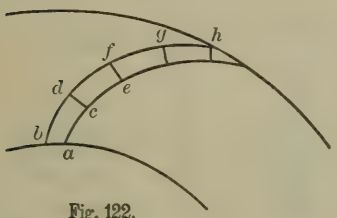


Fig. 122.

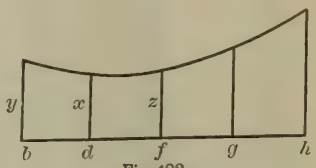


Fig. 123.

32. *To find the form of the free surface*, let the bucket be very narrow, so that a normal to one of the curves will be approximately normal to the other. Divide one side of the bucket into any convenient number of parts, as ac, cc, etc., and erect normals to the arc, as ab, cd, etc. Lay off these arcs on a right line. Compute the velocity at any point, as d, Fig. 122, by formula (87). Let x be the required depth at d; then because the velocity into the section equals q, the volume passing through one of the buckets per second, we have

$$x \,.\, dc \,.\, v = q;$$

$$\therefore x = \frac{q}{dc \,.\, v}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (88)$$

and similarly for all other sections. If only relative heights are to be found, the quantity q need not be found, for if y be the height at b, Fig. 123, then

$$y \,.\, ba \,.\, v_1 = q;$$

$$\therefore x = \frac{ba \,.\, v_1}{dc \,.\, v}\, y, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (89)$$

and by assuming any arbitrary value for y the relative value of x becomes known. Similarly, the relative heights at all other sections may be found

33. *To find the path of the fluid* in reference to the earth, proceed as in Article 21 of the discussion of the general case.

34. The following is taken from the report of the Commissioners of the Centennial Exposition, 1876, on Turbines, Group XX. The tests were for two minutes each. The revolutions and horse-powers here given are those corresponding to the best efficiencies :

Diameter of wheel. Inches.	Head in supply chamber. Feet.	Revolutions per minute.	Horse-power.	Efficiency, per cent.	No. of Buckets.	Kind of wheel.
30	31	255	95	85.0	10	Inflow.
24	31	302	67	77.0	14	Parallel.
24	30½	310	64	74.5	13	
27	30	291	76.8	80.3	16	
30	30	257	74	75.5	18	
25	31	288	46	82.0	12	Parallel.
30	29.2	258	80.5	78.7	13	In and down.
25	30	279	62.5	83.7	15	In and down.
27	30.4	246	53.2	73.6	14	Parallel.
36	29.6	197	66.2	83.8	26	Parallel.

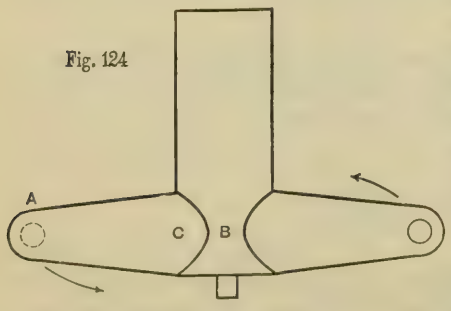
These tests were by no means exhaustive. It is not known that they were run for best effect. The distance from centre to centre of buckets varied from 4.3 inches to 9.5, and at these extreme values the efficiencies were about the same. The number of gate openings was less than the number of buckets.

TURBINES WITHOUT GUIDES.

35. *Barker's Mill.*

As ordinarily constructed, this motor has two hollow arms connected with a central supply chamber, with orifices near their outer ends and on opposite sides of the arms. There are no guide plates. The supply chamber rotates with the arms. The arms may be cylindrical, conical, or other convenient shape.

Fig. 124



This motor does not admit of an exact analysis, because the physical conditions existing within it are not definitely known, especially

that of the condition of the water where the arm C joins the supply chamber B. An approximate solution, sufficiently exact, may be made by assuming that the water enters the arm radially, and that the inner radius is zero; and that the water quits the arm in a direction perpendicular to the arm. These give

$$\gamma_2 = 0,\ \gamma_1 = 90^\circ,\ \alpha = 90^\circ,\ r_1 = 0,$$

and Equation (14) gives the well-known formula:

$$E = \frac{\omega r_2}{gH}\left[-\omega r_2 + \sqrt{\frac{2gH + \omega^2 r_2^2}{1 + \mu_2}} \right] \quad . \quad . \quad . \quad (90)$$

$$U = \delta QHE. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (91)$$

36. *Scottish and Whitelaw Turbines.*

These wheels have no guide plates, and differ from Barker's mill chiefly in having curved arms. The analysis is precisely the same as for the Barker's mill. The only practical difference consists in providing a curved path for the water.

37. *Jet Propeller.*

Let a narrow vessel, Fig. 125, be carried by an arm E about

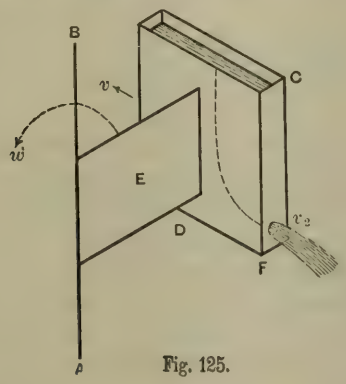


Fig. 125.

a shaft BA. Let water, by any suitable device, be dropped into the vessel, the horizontal velocity of the water being the same as that of the vessel. At F, the lower end of this chamber, let there be an orifice from which water may issue horizontally. The water may then be considered as entering the vessel or

bucket without velocity, and passing downward finally curve towards, and issue from, the orifice. It thus becomes a parallel flow wheel without guides, and we have, for the frictionless wheel,

$$r_1 = r_2, \quad \gamma_1 = 90^\circ, \quad \gamma_2 = 0, \quad \mu_1 = \mu_2 = 0, \quad H = 0,$$
$$p_2 = p_1 = p_a, \quad z_1 = 0$$

in Equation (8); hence, the velocity of exit relative to the orifice will be

$$v_2^2 = 2gz_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (92)$$

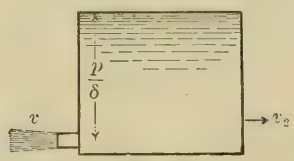


Fig. 126.

where z_2 equals the head in the supply chamber. Under these conditions the velocity of discharge will be independent of the velocity of rotation, if the rotation be uniform.

Equation (11) gives for the velocity of discharge relative to the earth

$$w = v_2 - \omega r_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (93)$$

Equations (19) and (14) give

$$U_1 = \frac{\delta Q}{g} v_2 \cdot r_2\omega. \quad . \quad . \quad . \quad . \quad . \quad . \quad (94)$$

This equation may be factored thus, $\frac{\delta Q}{g}$ is the mass of liquid flowing out per second; represent by M; Mv_2 is the momentum of the outflowing liquid per second. Mv_2r_2 is the moment of the momentum, and, finally,

$Mv_2 \cdot r_2\omega$ is the moment of the momentum into the angular velocity, and equals the work done.

Let $v = \omega r_2$ = the velocity of the vessel; then

$$w = v_2 - v, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (95)$$

$$U_1 = Mv_2v; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (96)$$

which equations are true whether the motion be circular, linear, or in any other path.

In practice, the velocity of the jet is produced by the pressure exerted by a pump, in which case z_2 in Equation (92) would be replaced by a virtual head, Fig. 126, equivalent to z_2; or

$$v_2^2 = 2g\frac{p}{\delta}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (97)$$

Also in the jet propeller the vessel, instead of having water supplied to it at the velocity of the vessel, picks it up from a body of water considered at rest; thus imparting to the water the momentum Mv, requiring the work per second

$$U_2 = Mv^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (98)$$

Hence the *effective* work done by a jet propeller picking up the water from a state of rest will be

$$U = U_1 - U_2 = M(v_2 - v)\,v. \quad . \quad . \quad . \quad . \quad . \quad (99)$$

The energy exerted by the pump will be that producing the velocity of water relative to the earth, or $\frac{1}{2}M(v_2 - v)^2$, plus that doing the work of driving the vessel; hence, the energy expended will be

$$\tfrac{1}{2}M(v_2 - v)^2 + U;$$

and the efficiency will be

$$E = \frac{U}{U + \frac{1}{2}M(v_2 - v)^2} = \frac{2v}{v_2 + v}. \quad . \quad . \quad . \quad . \quad . \quad (100)$$

This has no algebraic maximum, but approaches unity as v, the velocity of the vessel, in reference to the earth, approaches v_2, the velocity of the jet in the opposite direction relative to the orifice.

If $v_2 = v$, *the efficiency will be perfect* as shown by (100), but *no work will be done* as shown by (98). This would be the case of a vessel drawn by an external agency, or even floating along a stream; for the water backward relative to the vessel would equal the forward velocity of the vessel.

The mass of the jet per second will vary as the section of the orifice and velocity of the jet; and if k be the section of the jet, then

$$U = \frac{\delta}{g}kv_2(v_2 - v)\,v; \quad . \quad . \quad . \quad . \quad . \quad (101)$$

hence the same work may be done by enlarging the section k, and properly diminishing the velocity v_2 of the jet; but as v_2 is diminished, the efficiency is increased, as shown by Equation (101).

If $v = 10$ feet per second (about 6.8 miles per hour), we find

v_2	U	k	E
10	$0.k\frac{\delta}{g}$	∞	1.00
15	750 "	120.0	0.80
20	2000 "	45.0	0.67
30	6000 "	15.0	0.50
40	12000 "	7.5	0.40
100	90000 "	1.0	0.16

The sections k here given are for equal works, U. If the velocity of exit be constant, then will the work increase directly as the area of the section while the efficiency remains the same. These are without frictional resistances.

The effective pressure in driving the vessel will be

$$\frac{U}{v} = Mv_2 - Mv = P_2 - P,$$

in which P is the pressure equal and opposite to the jet, and P_2 a pressure which, if applied at the same point, would impart to the mass M the velocity v per second.

The speed of the vessel depends upon its form and the nature of the fluid; but the pressures due to the action of the jet will be the same whether it issue into a vacuum, or into air or water, or a more viscous fluid, so long as the true nature of a jet action is secured. If a block be placed before the jet so close to the vessel as to obstruct the flow of water as a jet, the conditions will be changed, and the forward pressure will then be due partly to the direct pressure exerted by the pumps. If a piston, having a long piston-rod projecting against a firm body outside the vessel, be forced backward, the forward pressure, effective in driving the vessel, would be that exerted by the pumps less the frictional resistances, but this is not a jet action. A jet implies that the water is *thrown* from the vessel. If the issuing stream meets with no resistance for the first few inches after leaving the vessel, it is quite immaterial what it meets later;

and the energy in the stream, in practice, removes the "block-like" nature, if any, of the water behind the vessel, so that a true jet is practically realized.

The great loss of efficiency of the jet propeller as a motor is due to the great loss of energy in the jet. The *entire* energy in the jet is lost. If the vessel be anchored, and the velocity of the jet be v_2, the pressure will be

$$P_1 = Mv_2,$$

the work will be

$$U = 0,$$

and the

$$\textit{energy lost} = \tfrac{1}{2}Mv_2^2.$$

If the speed v of the vessel is very small, then

$$P_1 = Mv_2,$$
$$U = Mv_2v, \text{ nearly},$$
$$\textit{energy lost} = \tfrac{1}{2}Mv_2^2, \text{ nearly},$$

and the energy lost will generally exceed considerably the useful work.

Conclusions.—From an examination of Tables II., III., VI., VII., the following conclusions are drawn:—

1. The maximum theoretical efficiency of the inflow wheel is perceptibly larger than that of the outflow, the width of crowns and the initial and terminal angles of the buckets being the same. This is due chiefly to the action of the centrifugal force opposing the velocity of the water in the inflow wheel, and to the smaller velocity and loss of energy of the discharging water.

2. Columns (10) in Tables VI. and VII. show that for the wheels here considered the loss of energy due to the quitting velocity is from 2.2 to 5.1 per cent. from the outflow, and from 0.9 to 1 per cent. for the inflow

3. The same tables show in column (2) that the efficiency for the inflow wheel is almost constant for the varying conditions here considered, while for the outflow there is considerable variation.

4. One of the most interesting and profitable studies to the theorist and practitioner is the effect upon the efficiency due to properly proportioning the terminal angle, α, of the guide blade.

It will be observed that all the efficiencies in Tables VI. and VII. exceed the corresponding ones in Table II. except the first in column (3) of Table II. In Table II. the terminable angle, α, is constantly 25°, while in Tables VI. and VII. it is less than that value, and in the highest efficiencies very much less.

5. It appears from these tables that the terminal angle, α, has frequently been made too large in practice for best efficiency.

6. That the terminal angle, α, of the guide should be for the inflow less than 10° for the wheels here considered; but when the initial angle of the bucket is 90°, and the terminal angle of the guide is 5° 28′, the gain of efficiency is not two per cent. greater than when the latter is 25°.

7. Tables II. and VI. indicate that the initial angle of the bucket should exceed 90° for best effect for outflow wheels.

8. Tables II. and VII. show that the efficiency is nearly constant for best effect of inflow wheels for all initial angles of the bucket between 60° and 120°.

9. The most marked effect in properly proportioning the terminal angle, α, of the guide is shown when the initial angle of the bucket is 150°. In this case the efficiency for the outflow when α is 25° is 0.744, Table II., but when α is $13\frac{1}{2}$° as in Table VI., it becomes 0.921. For the inflow, in the former case, it is 0.752, but when the angle is 3° as in Table VII., it becomes 0.918.

10. Since the wheels here considered have the same width of crowns and the same terminal angle of the bucket, the depths of the wheels of the same class will be proportional to k_2 for discharging equal volumes of water. Tables III., VI., VII., show that the section k_2 increases as the initial angle of the buckets increases, and that it must be greater for the inflow than for the outflow; hence the depth of the wheel must be greater for the inflow for delivering the same volume of water.

Since the discharge of the inflow wheel is from the inner rim, the depth must be $\sqrt{2}$ times as great as if it were from the outer rim in the wheels here considered. But the same quantity of water will do more work in the inflow wheel; hence the depth of the inflow wheel for doing the same work must be

$$\sqrt{2}\,\frac{\left(\frac{k_2}{E}\right)\text{of inflow}}{\left(\frac{k_2}{E}\right)\text{of outflow}}$$

times the depth of the outflow wheel. From Tables VI. and VII., for $\gamma_1 = 90°$ this will be 2.51; or the inflow must be about $2\frac{1}{2}$ times the depth of the outflow for doing the same work.

11. In the outflow wheel, column (9), Table VI., shows that for the outflow for best effect the direction of the quitting water in reference to the earth should be nearly radial (from 76° to 97°) but for the inflow wheel the water is thrown forward in quitting (column (9) Table VII.). This alone shows that the velocity of the rim in the latter case should somewhat exceed the relative final velocity backward in the bucket as is shown in columns (4) and (5).

12. In these tables I have given all the velocities in terms of $\sqrt{2gh}$, and the coefficients of this expression will be the part of the head which would produce that velocity if the water issued freely. In Tables VI. and VII., there is only one case, column (5) of the former table, where the coefficient exceeds unity, and the excess is so small, it may be said that generally, in a properly proportioned turbine with the conditions here given, none of the velocities will equal that due to the head in the supply chamber when running at best effect.

13. The inflow turbine presents the best conditions for construction for producing a given effect, the only apparent disadvantage being an increased first cost due to an increased depth, or an increased diameter for producing a given amount of work. The larger efficiency should, however, more than neutralize the increased first cost.

DXVII.*

A SIMPLE DIFFERENCE MACHINE.

BY GEORGE RICHMOND, NEW YORK CITY.

(Member of the Society.)

THE mere mention of a difference engine will recall to the mind the famous machine of Babbage.

In Knight's *American Mechanical Dictionary* is found a succinct account of this machine, and the "state of the art" down to recent date, and since it also refers to the principle on which such machines are based, it may better serve as an introduction to our subject than any explanation of the writer. It is accordingly transcribed below. More complete information may be found in *Babbage's Calculating Engines*,† to be seen in the library of this Society. As Babbage progressed, his ideas expanded so as to embrace an analytical engine, with the result—so frequent in such cases—of fully justifying the proverb, "*le mieux est l'ennemi du bien.*"

"*Calculating Machines.*—Babbage commenced one at the expense of the English Government in 1821, and worked upon it till 1833, when work upon it was suspended, after an outlay of £15,000. The portion completed is in the library of the King's College, London.

"This renowned but unfinished machine works on a peculiar arithmetical principle. The differences between numbers in a table are the elements out of which Mr. Babbage constructs the table itself, and on this account he calls his a *Difference Engine.* For instance, in a table of square numbers, 1, 4, 9, 16, 25, 36, etc., the difference between the first and second is 3; between the second and third, 5; and so we get a series 3, 5, 7, 9, 11, etc. Again, this series of first differences, if viewed in a similar manner, presents us with another and remarkable series, 2, 2, 2, etc. It is found that almost all numerical tables, when thus analyzed into successive orders of differences, end at last in a very simple series, constituting the materials—the atomic elements, so to speak—which, by addition, will produce all the numbers required in the table. The process of addition lies at the root of the whole method.

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* Presented at the New York meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions.*

† Published by Spon, London and New York.

"How to accomplish this by mechanism was the question which Mr. Babbage undertook to solve. The first term of the table and the first term of each order of differences being given, the whole table can be constructed from these elements, and dials were made to indicate these numbers. There are rows of dials to represent the successive orders of differences, and rows to represent the successive digits in a number ; and by an extraordinary assemblage of mechanism, the wheels to which these dials are attached act upon each other in an order determined by original adjustment. Each dial has on its edges the set of digits from 0 to 9. There are axes upon which the dials revolve ; teeth to the wheels behind the dials ; bolts which act on or into these teeth ; wedges to withdraw the bolts, and shoulders which regulate the action of the bolts on the teeth wheels ; all this determines the process of addition.

"When it is understood that the skillful Dr. Lardner occupied twenty-five pages in the *Edinburgh Review* in partially describing the complex action of the machine, and gave up other features as hopeless without a mass of illustrative diagrams, we shall be pardoned for not occupying space by attempting further description.

"*Harper's Magazine*, vol. xxx., pp. 34–39, gives some account of it, accompanied by a cut.

"G. & E. Scheutz, Swedish engineers, constructed a working machine, 1837–43, after studying the Babbage machine ; it was brought to England in 1854. It is stated to have been bought for the Dudley Observatory, Albany, N. Y.

"The Messrs. Scheutz have since completed one for the British Government, which was subsequently employed in calculating a large volume of life tables, which the authorities at Somerset House declare never would have been undertaken had not this machine been in existence."

It must be admitted that this description does not afford much encouragement to the hope of producing a simple and cheap machine to accomplish the same results, and it is evident that the problem must be attacked *ab initio* and pursued on different lines.

But since the time of Babbage the art of mechanics has been enriched by many new and ingenious mechanical movements ; and, above all, the electric current affords a means of transmitting motions from one point to another with such simplicity as to give the utmost freedom and elasticity in designing. While, therefore, the Babbage machine will remain a monument of ingenuity, it may be possible to construct an instrument of some practical utility without resorting to such serious complications.

In addressing a society of mechanical engineers, it is unnecessary to overload this article with constructional details ; it will therefore be confined almost exclusively to the kinematics of the machine proposed. Why the first model invariably fails to embody those principles in the best manner is a question which has not yet received a satisfactory answer.

For the purposes of illustration, we will take as a typical series that of cubes, namely, in which each term is the cube of the number of the term :

	Δ_1	Δ_2	Δ_3	Δ_4
1				
	7			
8		12		
	19		6	
27		18		0
	37		6	
64		24		0
	61		6	
125		30		
	91			
216				

From five terms we derive the successive orders of differences Δ_1, Δ_2, etc., the fourth difference disappearing. Hereafter the series can be continued by simple addition, as shown by the last diagonal line (in heavier type), thus :

$$0 + 6 = 6$$
$$6 + 24 = 30$$
$$30 + 61 = 91$$
$$91 + 125 = 216$$

By this process we have obtained the sixth term (216) of the series, and the set of differences, 0, 6, 30, 91, necessary for calculating the seventh term. The process of calculating this will give us the differences necessary for the eighth term, and so on *ad infinitum.*

It would perhaps seem that, without a machine, this process of continuing a series is sufficiently easy. In practice, however, the series are not of the simple nature of the one given as a type. The last difference is rarely absolutely zero ; and, in order that the series finally obtained shall be accurate to a given extent, it is necessary to take numbers with a very large number of digits, both in the first terms of the series and the differences obtained therefrom. If the table is required to be accu-

rate to six figures, all beyond the sixth digit will be dropped in recording the final results. To secure the accuracy of these results, if the table be a long one, it may have been necessary to work with 10 or even 20 digits. The arithmetical work would then be more formidable than the independent calculation of the individual terms of the series to the required degree of accuracy.

The ideal machine is one which would run night and day,

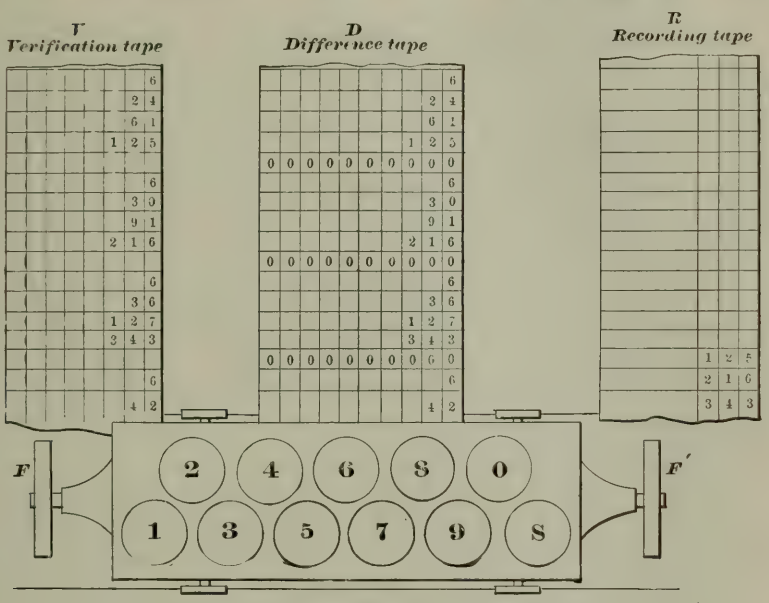

Fig. 127.

automatically perform these additions, and record the results. In such results we should have a confidence we could never accord to human calculations, for there is no "personal equation" to a machine.

Fig. 127 gives a diagrammatic view of the operation of the machine. A key-board similar to that of a typewriter carries keys marked 1, 2, 3, etc., and an additional key marked *S*. The writing of a number on this key-board determines the printing on one or more of three tapes, marked respectively verification tape, difference tape, and recording tape. The operation is commenced by writing (by hand) on the tape *D* the first complete set of differences 6, 24, 61, 125. When the typewriter takes his

place at the machine, only the first of these is visible through a slit, and his instructions are simply to write every number as it successively appears in the slit. Every number so written is printed on the verification tape, so that if any doubt is felt, reference can be made to it before proceeding to a new line. With this machine a new line is commenced, not, as in the ordinary typewriter, by running the paper back, but by running the key-board back, which, for this purpose, is mounted on a travelling carriage.

The act of bringing this carriage back moves the tapes V and D one line forward. The printing on the V tape is effected by a type-wheel F; that on the D tape comes from a totalizing device. While the tapes V and D receive an intermittent motion, the recording tape receives a periodic and intermittent motion. If there are four orders of differences in the series, then every fifth reversal of the key-board carriage determines the movement of the recording tape one notch, and the printing on it by the wheel F'. This fifth reversal also determines other modifications of the machine; it throws the mechanism governed by the key marked S into gear, and causes the machine to subtract the number read instead of (as previously) adding it to the totalizer. At the same time the wheel F is thrown out of printing contact, and the wheel F' into printing contact.

The process will be intelligible if we follow it through one complete cycle. The totalizer, which is some form of adding mechanism, being set at 00000, we take our place at the machine. The only number in sight is the 6 on the middle tape. This we proceed to write by striking the key marked 6. As a result, the carriage moves to the left one notch. As a further result, the number 6 has been placed on the totalizer and printed on the difference tape, as seen below. At the same time the number 6 has been printed on the verification tape. Moving the carriage back to its initial position (as we should do with a typewriter to commence a new line), we now find 24 brought into view. On writing this, 24 will appear on the verification tape, but 30 on the totalizer; viz.: 6 + 24, the effect being to add 24 to the 6 already on the totalizer. This number 30 is duly printed on the difference tape, where it appears below the 6 already printed.

In the same manner we print the numbers 61 and 125 as they successively appear in the slit, in consequence of which 91 and 216 are printed on the difference and verification tapes. The

next operation being the fifth, the wheel F' is thrown in printing contact instead of F; the machine subtracts from the totalizer the amount written, and records it on tape R. By the movement of the tape D, the row of 00000 would now be in view; the slit, however, is raised so as to expose the number 125, which is therefore written off a second time. This time, however, the result is to produce (by subtraction) a row of 00000 on the totalizer, which are printed on the D tape, being the row below 216. This completes the cycle, and the effect is that the first result belonging to the series is printed on the recording tape. The complete operation, though requiring rather a lengthy description, would be actually performed in a few seconds. It will be observed that the tape D now contains the set of differences 6, 30, 91, 216, necessary for the next operation. These are written off in quick succession as they appear in the slit, with the result that 216 takes its place as the second result on the recording tape.

The calculation of tables by the method of finite differences is thus reduced to purely mechanical work, which, with a little practice, can be performed with great accuracy and rapidity. With ordinary care the verification tape should insure absolutely correct results. Should an error occur, its position may be readily located, and only the work following the first deviation on the verification tape is lost.

Nor is it difficult to see how the operator may be eliminated. The appearance of a number in the slit determines the depression of the corresponding key, and this is the only independent motion to be produced. It is only necessary, therefore, to present those numbers in such a conventional form as to be identified by mechanism. The Jacquard principle will occur to every one; but in the meantime it may be noticed that while the keys are ten in number, they can be all operated by the combination of *four* independent motions.* For example, let the wheels of the totalizer carry, instead of the ordinary figures, the conventionalized forms in Fig. 128, the small circles within the squares representing either an embossed surface or perforation, produced on the tape by impression against the totalizer wheels.

* Examples of such combinations may be seen in the Hammond and Crandall typewriters. The machine now under consideration was suggested while designing a typewriter in which six keys sufficed to write a complete alphabet, seven keys two alphabets, etc.

The operator can now be replaced by a mechanical feeler of the form shown (enlarged) in Fig. 129. If the conventionalized figures consist of perforations as shown in Fig. 128, then a, b, c, d, are small metallic plungers fitting in the head A. The tape is presumed to pass over a metallic plate. When A is presented

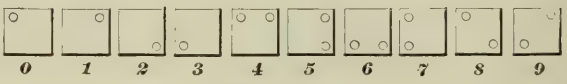

Fig. 128.

to number 0, Fig. 128, the plunger b, being opposite a perforation, will, by metallic contact, close the circuit of a current governed by it, in consequence of which the key marked 0 on the key-board will be depressed. If the number be 5, then c and d will make contact, and the combination determines the depression of the key marked 5. In this case the key-board may travel to its full extent and reverse itself, or the fact that no contact at all is made may determine its reversal. The machine can now be actuated by a small dynamo, and will quietly grind out tables to any extent desired. The manner of treating negative differences and negative results will be seen hereafter; it is sufficient to note that on the difference tape negative numbers will appear as arithmetical complements, and negative results would ordinarily be printed in the same form. They can, however, be printed as negative numbers, the fact being indicated by a difference in type.

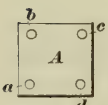

Fig. 129.

It may be remarked in passing that by the perfection of photo-engraving we are liberated from the necessity of imprinting the results in a matrix. Moreover, this removes any limitation as to size of the printed figures. They can be made of any size to suit the requirements of the machine for spacing, the results being photo-engraved from the recording tape on any scale desired.

The operation of the mechanism to obtain this result will be most easily understood by building it up synthetically, and the possibility of combining all the necessary motions without serious complication would seem to reside in the method of producing the fundamental motions for adding and recording. The writer regrets that he is unable to present a complete machine to the consideration of this Society. During a vacation he made,

under rather adverse conditions, models exhibiting the principal movements, from photos of which Figs. 130, 132, 133, and 134 are printed. As it seemed doubtful whether he would ever prosecute the idea to its legitimate end, it was deemed advisable to put it on record in its present condition.

FIG. 130.

Fig. 130 shows the application of the fundamental movements to what will be readily recognized as a cash register. With a view of making the investigation self-supporting, this machine was intended to furnish the funds necessary for the perfecting of the more complex mechanism. It is introduced because it

illustrates the extreme simplicity of the adding and recording mechanism. A frame swinging on the shaft seen in the rear (part of the cover being removed), carries a bank of keys, numbered in this case 5, 10, 15, etc. Under these keys is a barrel having twenty projecting pegs, dividing the circumference into twenty equal parts, each peg revolving in a circle directly under a slot seen in each key. The keys are flat bars of steel attached to a bar in the rear and held by gentle pressure against the cross bar above them. In this position their front extremity stands above the cross bar of the frame under them, and the pegs all pass clear of the keys. When, however, the finger is placed on one of the keys, it is at once brought into contact with the front bar of the frame, in which position its slot enters the path of the corresponding peg, so that the barrel can be revolved only to the point at which the peg enters the slot. If, for ex-

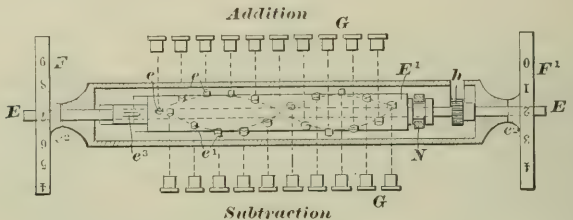

Fig. 131.

ample, the key marked 50 be depressed, the barrel can make only one-half revolution, and so on. The frame is held in a horizontal position by springs or otherwise, and to operate the machine the pressure on a key is continued until it and the frame swings to its lowest position. The rotation of the barrel is secured by the gearing of a pinion on it (see Fig. 131) into a sectorial rack seen in Fig. 132. This rack is held in position independently of the swinging frame. The barrel revolves until its peg enters the slot of the particular key depressed, after which the rack, being interlocked with the pinion, follows the frame in its swinging motion. The shaft of the barrel projects through each end of the frame, carrying type-wheels or other devices. In Fig. 130 the type-wheel is removed to show the totalizer, which, in this case, is simply a small engine counter actuated by the backward or forward motion of the barrel-shaft.

When the numbers to be added consist of several digits, the

swinging frame, which is now made as light as possible, must be mounted on a travelling carriage. One form of this arrangement is seen in Figs. 132 and 133. The swinging frame (Fig. 133), now carrying only ten keys (or eleven, with the subtraction key), is pivoted on the axle seen projecting through the

FIG. 132.

sectorial rack, and with the exception of the key-board is hidden by the front cheek of the travelling carriage. This carriage runs on steel ways provided at the upper left-hand and lower right-hand corners. In Fig. 133 a front view of this track is obtained, which is double, to prevent jumping in drawing the

carriage back. The screw heads right and left of the hook indicate the position of the rollers. The carriage is shown in mid-

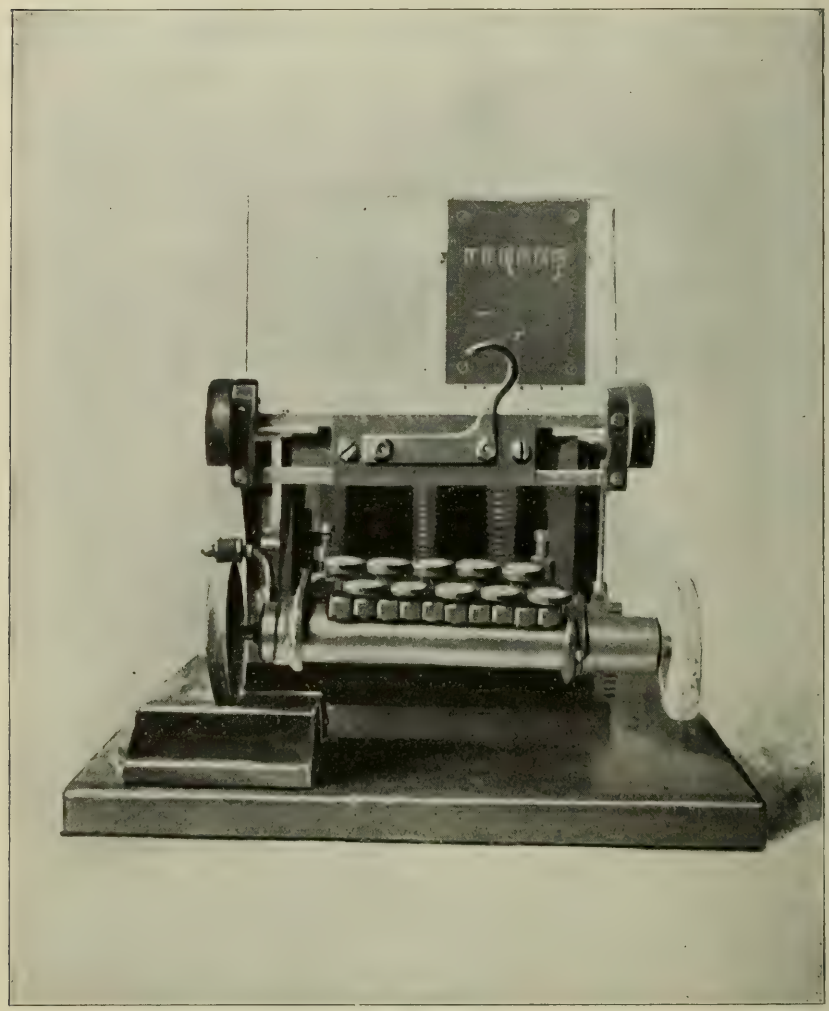

FIG. 133.

position; to bring it back, the thumb is placed in the hook shown.

Each time the swinging frame is depressed, the carriage is moved one notch to the left by a mechanism similar to that of the paper feed of a typewriter, but acting conversely. This will

be understood from a rear view of the machine (Fig. 134). The shaft there seen is that on which the swinging frame vibrates, and with it the feed mechanism. A number having been printed and the swinging frame released, it is brought back to its normal position by the action of the springs seen in the background. At this moment the fixed pawl to the right just clears the rack, and the carriage, under the influence of a coiled spring not shown, is moved to the right. The movable pawl to the left remains in gear with the rack, and by it is carried back against a feeble spring until it encounters the set-screw shown, which limits the feed. On the next downward swing of the frame, the movable pawl leaves the rack and shoots forward to the next notch. In drawing the carriage back, only the movable pawl is in gear, and being pivoted at the point indicated by projecting rivet, ducks under the teeth without resistance.

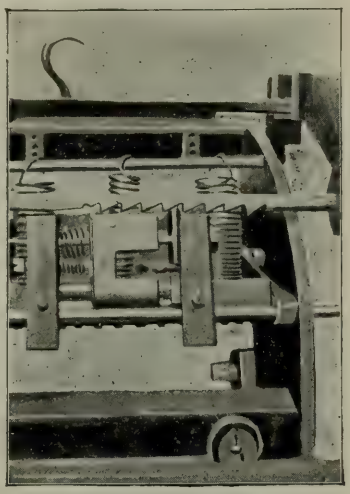

FIG. 134.

The motion transmitted to the totalizer is not the arc turned through by the roller, but that of the rack which is complementary to it. By properly adjusting the pegs, the keys will still indicate the amount of motion actually transmitted. One arrangement for this transmission is seen on Fig. 6, where a small rocking beam transforms by means of long connecting rods the angular motion of the sectorial rack to the straight up-and-down motion of a sliding piece. It was ascertained that the irregularities introduced by this transformation were insufficient to affect the accurate working of the mechanism, which will be easily understood when it is remembered a totalizer wheel is never moved less than one-tenth of a complete revolution.

This transformation is not absolutely necessary. It was designed to accommodate a simple form of totalizer sketched in on Fig. 133, which is also shown in detail in Figs. 137 and 138, but at present we are interested only in the fact that the units,

tens, etc., wheels are independently actuated by pushing up vertical slides, the extremities of which are seen to project below the casing of the totalizer in Fig. 133. The intervals between these slides correspond to the spacing on the rack (Fig. 134). Suppose the number

67892

is to be added, the corresponding keys (beginning at the right hand) are struck in rapid succession, as in typewriting. What takes place is this: On striking the key marked 2, the barrel revolves till a peg situated $\frac{8}{10}$ of the circumference from the starting-point enters its slot. The barrel being then arrested, the remaining $\frac{2}{10}$ is performed by the rack and transmitted to the pusher seen in Fig. 132. This motion, $\frac{2}{10}$ being transmitted to the first projecting slide in Fig. 133, adds 2 to the unit wheel of the totalizer. The instant the finger is removed from the first key, the frame swings back, and on regaining its normal position, is fed to the left one notch by the mechanism of Fig. 134. When 9 is struck, the pusher is now under the second slide, and the 9 is added to the second wheel of the totalizer. When the whole number is thus written and added, the carriage is brought back to the starting-point by placing the thumb in the hook seen in Fig. 133.

At this stage the machine forms a cash register adapted for purchasers of any amount whatever; one wheel printing the amount on a ticket, the other recording them consecutively on a tape (which may be enclosed or in view of the purchaser), while the totalizer gives the total of the receipts for the day.

Subtraction is performed by addition of the arithmetical complement. A method too well understood to need explanation. The barrel (Fig. 131) is seen to contain two distinct rows of pegs spirally arranged. Each peg on the one series is the arithmetical complement of the corresponding peg on the other series. The depression of the key marked *S* slides the barrel along on its shaft, so as to bring the second series in gearing position relatively to the keys. A type-wheel is seen at each end of the rotating shaft (Fig. 133). These are seen one behind the other in Fig. 135, from which it is apparent that only one can print at a time. The sliding connection between the barrel and its shaft is rifled so that the longitudinal motion necessary to bring the second series of pegs in gear, also rotates the shaft

one-twentieth of a revolution relatively to the barrel. This throws the first type-wheel out of printing contact, and the second or complementary wheel into printing contact, as seen in Fig. 135. In this manner the left-hand wheel prints only added numbers, and the right-hand only subtracted numbers. The apparatus as thus far developed constitutes a balancing machine. The Dr. items will be printed on the left-hand, and the Cr. items on the right-hand, tape, while the totalizer will always show the balance. If the Cr. items upon the whole exceed the Dr. items, the balance will appear as an arithmetical complement; the nature of the balance may be, therefore, instantly recognized.

In Fig. 136, the two wheels are combined; it will therefore

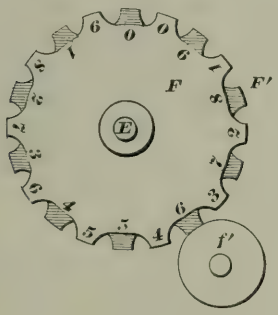

Fig. 135.

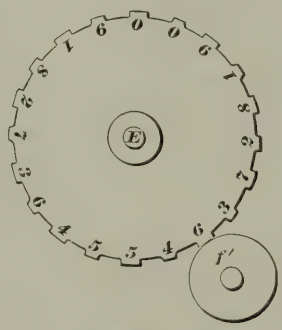

Fig. 136.

print both positive and negative numbers, but in different type. This is of use in treating positive and negative differences or results when used as a difference engine.

To adapt it to this purpose there only remain the motions for feeding the tapes along, and printing from the totalizer. The former are easily derived from the motion of the carriage, which occurs at the completion of each line. The printing of the totalizer results may be effected *en bloc* by the return of the carriage, or *seriatim* by a hammer actuated from the swinging frame striking on a transparent tape. This is perhaps preferable, for the numbers on the totalizer will now appear in their natural form (not the obverse), which may be an advantage in using the machine for other purposes than as a difference engine. These details have been sufficiently worked out to indicate their entire practicability; they are not given, however,

since the writer believes a remodelling of the machine on the general lines indicated is desirable, especially with a view of making it absolutely self-acting as above indicated.

The totalizer is shown in section (Fig. 137), and in plan (Fig. 138). The carrying is effected by making one tooth of the ratchet l, viz. : l^2, of extra length ; when this passes under the pawl l' it lifts the set-screw o' and lever o, the motion being

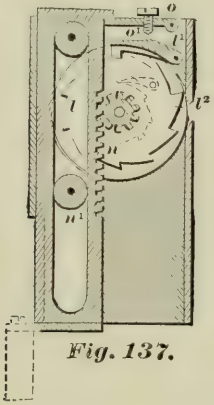

Fig. 137.

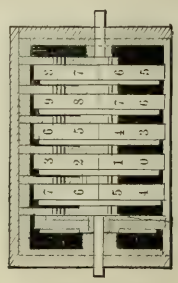

Fig. 138.

transmitted to the *next* slide. The slides fit loosely in their slots and run on friction rollers, n'; the wheels are strung on the axle n. Any totalizer having the qualities of compactness and independent action of the wheels, together with great lightness of the moving parts, would answer the purpose. The body of that shown consists of a single block of metal which, when it leaves the milling and boring machines, is ready to receive a series of duplicate parts without further adjustment.

DXVIII.*

A NEW RECORDING PRESSURE GAUGE FOR EXTREMELY LOW RANGES OF PRESSURE.

BY W. H. BRISTOL, HOBOKEN, N. J.

(Member of the Society.)

SINCE describing and exhibiting a sinuous tube recording pressure gauge† at the New York meeting of the society in November, 1889, many of the instruments have been placed in successful operation; but it has been found impracticable to make gauges on the flattened sinuous tube principle which would be sufficiently sensitive to register extremely low ranges or variations of pressure. Such are the variations due to a difference of one-tenth inch head of water, as in the case of illuminating gas in street mains, where the total range rarely exceeds two ounces per square inch, or its equivalent, four inches head of water. For such extremely low pressure, it was necessary to offer a very large area for it to act against. This has been accomplished by employing a series of corrugated diaphragms A placed as shown in cross section in Fig. 139. The diaphragms are arranged in pairs and joined, as shown, with a continuous opening through the line of centres

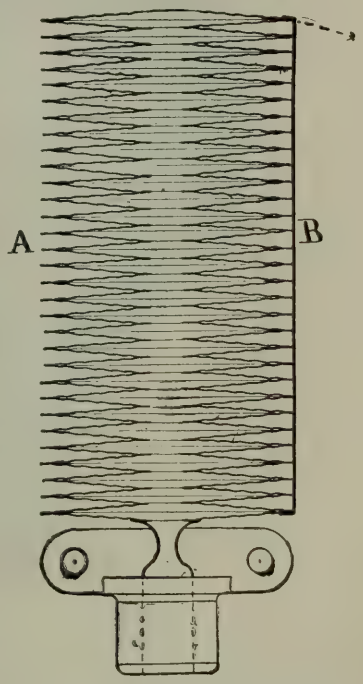

FIG. 139.

* Presented at the New York Meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the Transactions.

† Transactions A. S. M. E., Vol. XI., p. 225, No. 368.

of the different pairs, thus permitting the pressure to exert itself simultaneously on the interior of every pair, the effect of variations being to produce an elongation of the whole.

This arrangement of diaphragms is employed in the construction of certain self-registering barometers, the small motion of the diaphragms being made available by a train of multiplying mechanism. In the gauge now exhibited, the disadvantage of

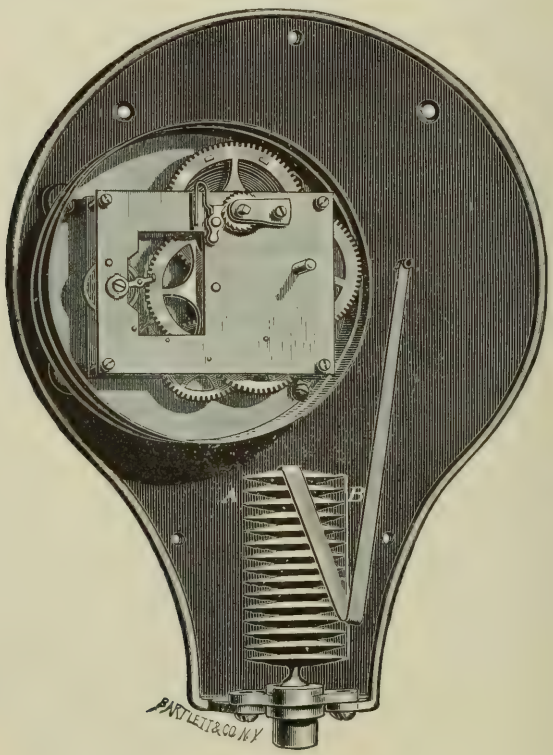

FIG. 140.

using multiplying devices is entirely obviated by simply securing a flexible strip *B* along the edges of the diaphragm tube, as it might be called. The effect of applying the flexible strip is two-fold : first, it stiffens the diaphragm tube as a whole ; and second, it performs the most important function of resisting the tendency of the pressure to elongate it, which naturally results in producing a greatly multiplied lateral motion.

As in the sinuous tube, the motion thus produced by varia-

tions of pressure is ample for directly indicating or recording in connection with a moving chart. By the use of a large number of diaphragms, as shown, it is evident that the change of form of each individual member is very slight for complete range of pressure. It follows that none of the diaphragms will be strained to their elastic limit, and all danger of the gauge taking permanent sets will be avoided. In the application of the

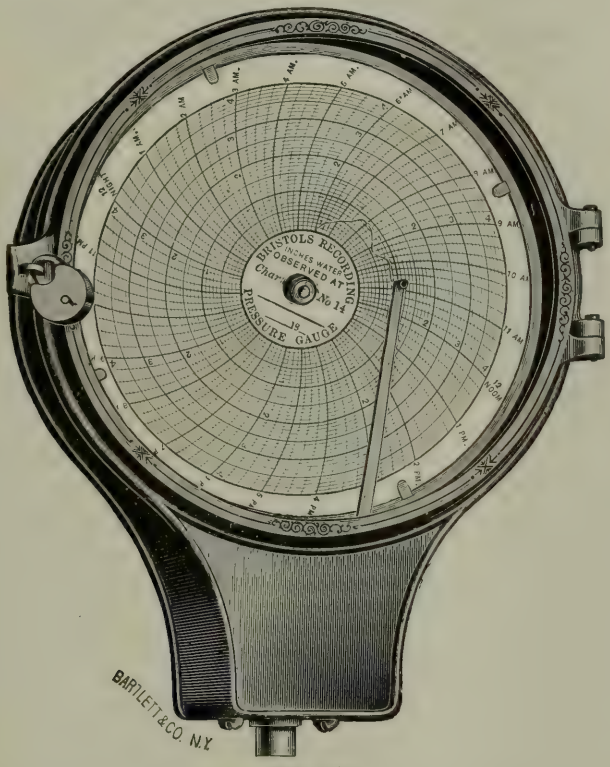

FIG. 141.

diaphragm tube to a recording gauge it is mounted on a back as shown in Fig. 140.

A recording pen is attached directly to the end of the diaphragm tube, and a clock is provided, as shown, timed to revolve a dial, in the plane of movement of the pen, once in twenty-four hours.

In Fig. 141 the gauge is shown complete, with chart, ready for application. The small graduations on the chart indicate tenths of inches head of water.

This form of tube is not limited to recording gauges for light pressures only, as it could be equally well adapted for all ranges if the diaphragms are properly proportioned as to size and thickness of metal.

There are other practical applications of this form of tube, if constructed on a large scale, as considerable motion and power could be developed; sufficient, it is believed, to operate directly, without intervening mechanism, regulators, dampers, valves, and especially that class of automatic devices in which pressure is the initial motive power.

DISCUSSION.

Mr. R. Van A. Norris.—I should like to ask Mr. Bristol if he has ever applied his gauge to record the pressure used in ventilating buildings or mines. The Pennsylvania law requires coal operators to keep automatic records of either the speed of ventilating fans or of the water gauge (usually depression) in them; it strikes me that Mr. Bristol's gauge could be applied to record this, which is usually between the limits of $\frac{1}{4}$ to 4 inches water gauge. Occasionally they will run as high as 5 inches, but it is very rare. I know of only one instance in my experience of a 5-inch water gauge in Pennsylvania.

Mr. Bristol.—That is an application which has not occurred to me yet, because I never had any connection with mines or mining business. I can see no reason why it would not be very applicable to such a place. The gauge in its present form as exhibited has a total range of 4 inches head of water, and would, I believe, be directly applicable for recording pressures used in mine ventilation.

If it was an exhaust of from $\frac{1}{4}$ inch to 4 inches to be recorded, the same instrument could be adapted by placing the flexible strip on the opposite side of the system of corrugated diaphragms, so that the exhaust or suction would produce a deflection to the right, the same as is now produced in the model by a pressure (Fig. 140). Exhaust has a tendency to shorten the system of diaphragms, and as their tendency is resisted by the flexible strip, a multiplied lateral deflection will be produced. The direction of deflection will be opposite to that produced by pressure. It therefore follows that the instrument may be arranged to record both exhaust and pressure upon the same chart, if desirable. I expect there will be many applications

developed as Mr. Norris suggests now. I am very glad of an opportunity to learn of this.

Mr. Jesse M. Smith.—I would like to ask Mr. Bristol whether there is any temperature correction necessary. If the instrument were placed in a room, say at 60°, and the temperature went up to 70° or 80°, will there have to be a correction on account of that change of temperature? I would also like to ask whether he has used this as an air thermometer for continuous use in measuring the temperature of the gases escaping from a boiler.

Mr. Bristol.—The only applications which have been made thus far are the measurement of pressures of gas in street mains; but, as shown by this experiment here, I can see no reason why the instrument would not be very applicable to the measuring of temperature of furnace gases, for the instrument itself would not have to be exposed to high temperatures. It could be at one side, and it is only a matter of arbitrarily graduating the chart, once for all, to suit the volume of air which is in the pipe leading to the gauge by some standard thermometer. The pressure would only practically be affected by the temperature of the furnace gases themselves. I expect to perfect air thermometers for high temperatures, and, if necessary, provide for changes of atmospheric temperature.

Answering the other question, as to the effect of temperature on the instrument when used as a pressure gauge, I would say that I have not made any actual experiments other than taking a Bunsen burner, and applying the flame directly to the tube itself to see if the extreme temperature changed its form, and I could not see that it did. That would be about as severe a test as you could possibly give it (applying flame of Bunsen burner to model). You see, even with extreme heat directly applied to the tube, the indicating hand does not move from the zero point. From this experiment I came to the conclusion that an ordinary atmospheric change of temperature would not affect it. The result would be simply a cubical expansion, which is about eighteen or nineteen millionths for a degree.

Mr. James Hartness.—I would ask Mr. Bristol if the same result would be accomplished if he left that pipe plugged up, or if he put a heat on that tube to the pressure gauge.

Mr. Bristol.—I expect that the tube will move, as the apparatus is in condition to act as a thermometer. As there is considerable volume of air confined in the tube itself, upon heating

the tube it will be expanded, producing a pressure which will act on the tube and make it deflect. I will try the experiment. I have not tried it before applying flame of Bunsen burner directly to tube of model, the outlet being closed. I can see indicating hand move. It moves about one-eighth of an inch. Of course, that is an extreme temperature I have applied, probably a difference of 100° right in the tube itself, which is probably more than you would have in any place where the instrument would be put, due to atmospheric changes of temperature.

When the instrument is applied as a pressure indicator or recorder, as, for instance, on a street gas main, any effect of atmospheric temperature would have to produce a difference throughout the whole system before there would be any difference indicated by the gauge.

Mr. Frank H. Ball.—One more question. This instrument seems to be almost perfect. The question has just occurred to me whether the scale of the instrument would be affected by heat. We notice that when heat is applied to the diaphragms, with the pointer at zero, no motion takes place; but if at the same time the instrument was used in the usual manner, would the resulting record be the same as when the diaphragms are cold?

Mr. Bristol.—It is all a question whether the elasticity of the metal is changed by an ordinary change of temperature. I cannot answer that question. I cannot see any reason why it should be, though, of course, if we should heat the diaphragms up to anything approaching a red heat, it would lose its elasticity; but I think, within moderate ranges, that that element would not appear.

Mr. Gus C. Henning.—I would say that experiments made by Professor Martens show that up to 950° F. there are no changes in elasticity; that metals show the same modulus and limit of elasticity up to at least 950° F.; beyond that there might be minute variations, but there would be no changes for temperatures within which the instrument itself could exist.

DXIX.*

EXPERIMENTAL DETERMINATION OF THE HEAT GENERATED PER CANDLE POWER BY OIL AND GAS LAMPS.

BY D. S. JACOBUS, HOBOKEN, N. J.

(Member of the Society.)

In the course of a general investigation, recently undertaken by the Department of Tests, at Hoboken, to determine the relative cost of obtaining the average illumination afforded by gas and kerosene lamps in railroad service, it was proposed to determine the amount of heat generated per candle power with each kind of illuminant, and this element of the general problem was assigned to the writer.

The calculation of the theoretical heat of combustion of the gas and kerosene from their respective chemical analysis is, of course, one solution of such a problem ; but it was desired to check the results of such a calculation by a measurement of the heat, after it had distributed itself to the air surrounding the lamp, and supporting the combustion, under as nearly as possible the conditions of a lamp in railroad service.

The determination of quantities of air flowing through any space, by the measurement of velocities with the best forms of anemometers, affords results so unsatisfactory that it was deemed necessary to devise some other method for such measurement. This having been, we believe, successfully accomplished in the present case, it is the object of this paper to describe the method, and also to place upon record, in detail, the measurements of candle power which were necessary to establish the average illumination obtainable from the best forms of kerosene lamps.

The general idea of the method employed to measure the total heat generated is as follows :

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* Presented at the New York meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the Transactions.

The lamp is surrounded with an air-tight wooden chamber about four feet square, with a circular air inlet pipe at the bottom, and another near the top. When steady action is established, the temperatures of the air entering and leaving the chamber were determined by thermometers located at a sufficient number of points, in each of the air pipes, to establish a true average for the entering and exit currents. An anemometer is uniformly moved about the cross-section of the inlet pipe, and the candle power simultaneously determined by a photometer mounted at the side of the chamber (see Fig. 142). The lamp is then removed from the chamber, and a steam coil substituted, as represented in Fig. 143. The condensation of steam in this coil is adjusted so that the anemometer and thermometers give practically the same readings as when the lamp was in the chamber. The total heat given by the lamp is then determined from the latent heat of the steam condensed, proper allowance for differences of radiation, effect, etc., being made, as explained below.

It is evident that by this method we avoid having to interpret the readings of the anemometer as absolute velocities. The only means of doing this is to calibrate the anemometer by moving it at uniform velocity through the air, as, for instance, by attaching it to the end of a radius arm rotating at uniform speed. The condition of the anemometer when so calibrated differs so much from those surrounding it, when located in the inlet pipe, that in the present case the amount of air differed 20 per cent., when thus determined, from the true amount as deduced from the heat of the condensed steam and the observed temperatures of the entering and exit air.

The agreement between the heat determined by the condensed steam method and by analysis is as follows:

Heat generated in B. T. U.	By chemical analysis.	By condensed steam method.
Per cubic foot of oil gas at 85 degrees Fahr	1,280	1,250
Total heat per lb. of mineral seal kerosene oil, argand burner	19,000	18,830
Total heat per lb. of mineral seal kerosene oil, double wick flat flame burner	19,000	18,750
Total heat per hour per candle power in B.T.U. Oil gas	130	127
Total heat per hour per candle power in B.T.U. Kerosene	193	191

The candle power measurements showed that the most improved form of argand railroad lamp consumed the same amount of kerosene per candle power as the best form of flat flame lamp, in which two wicks are used with an air supply between them, the combustion of the two wicks uniting so as to form a single flame.

The maximum light which could be steadily maintained, with the attention available in railroad service, with the argand flame, was 16 candles, and with the flat flame, 8 candles.

The oil gas was burned in a four-flame Pintsch burner, affording, under the average condition of railroad service, 32 candles.

The results of the experiments are given in detail in Tables I. and II.

TABLE I.

HEAT GENERATED BY GAS AND OIL LAMPS.

Class of lamps.	Number of tests.	Velocity of air over car roof in miles per hour.	Heat per hour per 32 candle power in B. T. U.		Total heating power per cu. ft. of gas or per lb. of oil in B. T. U.
			Total.	Imparted to air around the lamps.*	
1	2	3	4	5	6
Gas	9	0	4,045	....	1,233
"	10	0	4,084	....	1,261
"	4	0	....	3,536	....
"	3	40	....	1,847	....
Oil argand bur.	12	0	6,278	....	18,830
"	11	0	5,971	....	....
"	6	0	5,839†	3,583	....
"	5	40	....	1,942	....
"	7	40	....	2,300	....
"	21	40	....	2,030	....
Oil flat flame	28	0	....	....	18,750

* The arrangement of the currents of air in the testing box should not be considered as a copy of the currents in a car. The results given in the table simply indicate that the ventilator carries away a great portion of the heat.

† This quantity is not determined by the direct method of measuring the total heat, but is calculated by measuring the heat leaving the ventilator, and adding it to that given up to the air about the lamp. The direct determinations only are employed in drawing conclusions.

TABLE II.

RATE OF OIL CONSUMPTION IN ARGAND AND FLAT FLAME LAMPS, TWO FLAMES BURNED IN EACH TEST.

Number of test.	Duration of test in hours.	Class of flame.	Oil burned per hour in lbs.	Candle power sum of two flames.	Oil per hour per 32 candle power in lbs.
12	4.5	Argand.	.333	32.2	.331
21	2.0	"	.344	33.5	.329
23	5.0	Flat.	.152	15.9	.306

DESCRIPTION OF APPARATUS EMPLOYED, AND OF THE GENERAL METHODS OF MAKING THE TESTS.

The lamps tested were taken from cars in which they had been in active service. Each lamp was suspended from a section of a car roof. These sections were cut from a car that had been in service, and were covered with roofing tin in the usual way.

Two varieties of oil lamps were tested. One of these had argand flames, and the other flat flames. The flat flame lamp had two wicks per burner, between which a portion of the air for combustion was admitted. The gas was burned through a four-flame Pintsch burner.

The general arrangement of the apparatus is shown in Fig. 142. *A* is a box about 4 feet square, in which the lamp to be tested is placed. The top of the car roof section *J*, in all tests except those in which the total heat is measured, projects slightly above the top of the testing box *A*. *L* is a glass door through which the conditions of the lamp flames may be observed, and *F* is a door that is opened when the candle power is measured. In making heat measurements the doors *L* and *F* are closed. The air then enters through the galvanized iron pipe *B*, which is 12 inches in diameter, and passes out through the lamp ventilator *M* and the pipe *C*, which is 10 inches in diameter. *H*, *H*, *H*, *H*, *H* are five thermometers used to measure the exit temperature. These are placed so that their bulbs are in various positions in the same cross section of the pipe. *I* is a meter for measuring the gas used by the gas lamp.

In tests where the effect of the velocity of the air over the top of the car is included, the blower *D* furnishes air through the

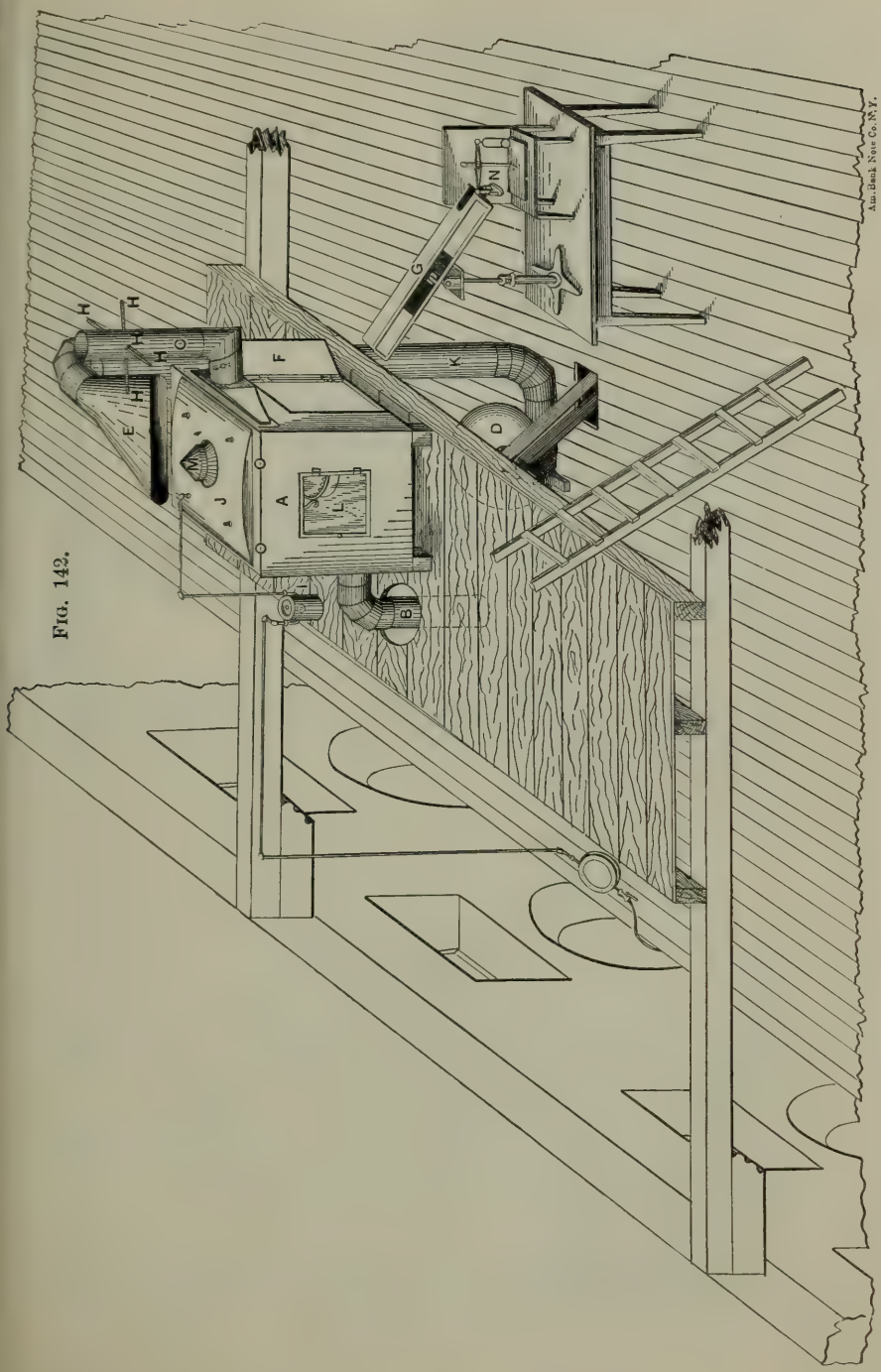

FIG. 142.

12-inch pipe K to the nozzle E. This blower was made to run at such a speed that the velocity of the air over the ventilator M was 40 miles an hour.

The candle-power was measured by means of the photometer G. N is the candle-balance.

In the tests the total heat developed by the lamp, four strips, one of which is marked O, O, in the figure, were removed, so that the air from the box had free access around the edges of the car-

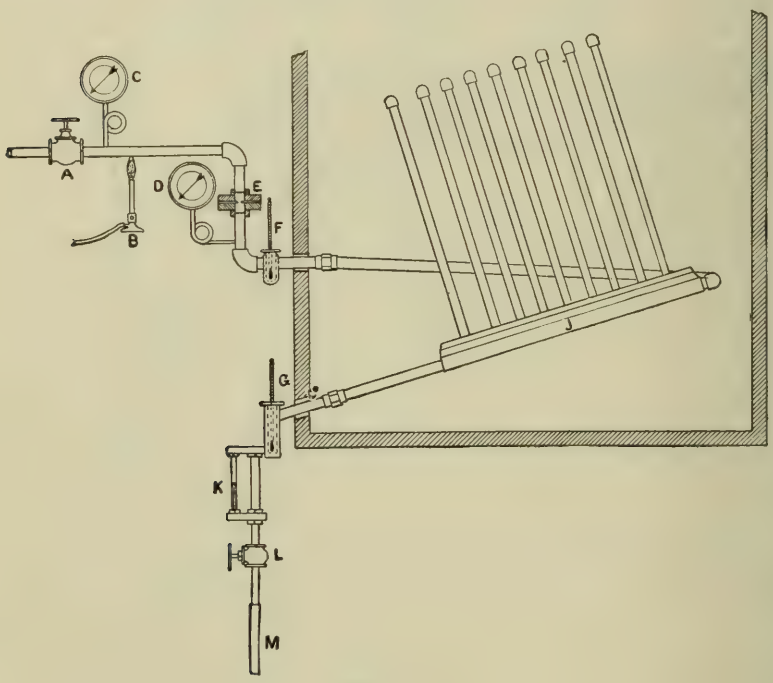

FIG. 143.

roof section, and a special cover, which was high enough to clear the ventilator M, was placed over the top of the testing-box. The pipe C was removed from the side of the testing-box, and placed on a flange fastened to the top of the special cover. In the tests for total heat, therefore, all the air that entered through the pipe B passed out through the pipe C.

Anemometers were employed to measure the velocity of the air in the pipes B and C.

To make a complete heat measurement the lamp is placed in the testing-box A, as already described, and all data recorded.

The lamp is then removed, and in its place is substituted a steam radiator. The radiator is furnished with sufficient steam to heat the air the same amount and produce the same anemometer readings as were observed in the test of the lamp. The heat given up by the radiator will then be same as the heat generated by the lamp, and may be measured by weighing the steam condensed by the radiator. The arrangement of the radiator coil is shown in Fig. 143.

The radiator *J* is placed at an angle so that the condensed steam will flow freely from it. The steam furnished to the radiator is superheated in order that the total heat it contains may be accurately estimated. The Bunsen burner *B* is employed to heat the steam sufficiently to give the desired amount of superheating after passing through a throttling orifice at *E*. The amount of steam entering the radiator is controlled by means of the valve A. The gauge *D* gives the pressure of the steam entering the coil. *C* is used to assist in preserving a uniform rate of flow through the orifice *E*. *F* and *G* are thermometers inserted in mercury wells to measure the temperature of the superheated steam at entrance and of the water at exit. The exit water is preserved at a constant height in the water-glass *K* by throttling at the valve *L*. In order to prevent loss by evaporation, the condensed steam is led through the rubber tube *M* under the surface of cold water, in which it is finally weighed. In some of the tests the radiator would have been too large for the work if it had been completely filled with steam. In these tests a certain amount of air was left in the radiator, which reduced the rate of condensation to the desired amount.

To eliminate leakage in the testing-box shown in Fig. 142, all the joints were carefully glued together. The doors were made a good fit, and after closing them, soft putty was spread over the cracks around them. The cracks at the sides of the movable pieces *O*, *O*, were covered with thick brown paper pasted on with flour paste. The pipe *C* was thickly covered with felting. All the exposed portions of the apparatus shown in Fig. 143 were covered with felting.

In a preliminary test the joints at the sides of the movable pieces *O*, *O*, were not covered with the strips of paper. Although the joints were well made, the pieces being fitted in place as accurately as possible, the leakage of air through them was found to seriously affect the readings. It was for this

reason that all joints in the box in all the tests employed in deducing the heat data were closed by either pasting paper over them, or by means of soft putty.

The method just described is that employed in all the tests, but there are necessarily corrections to be made to allow for

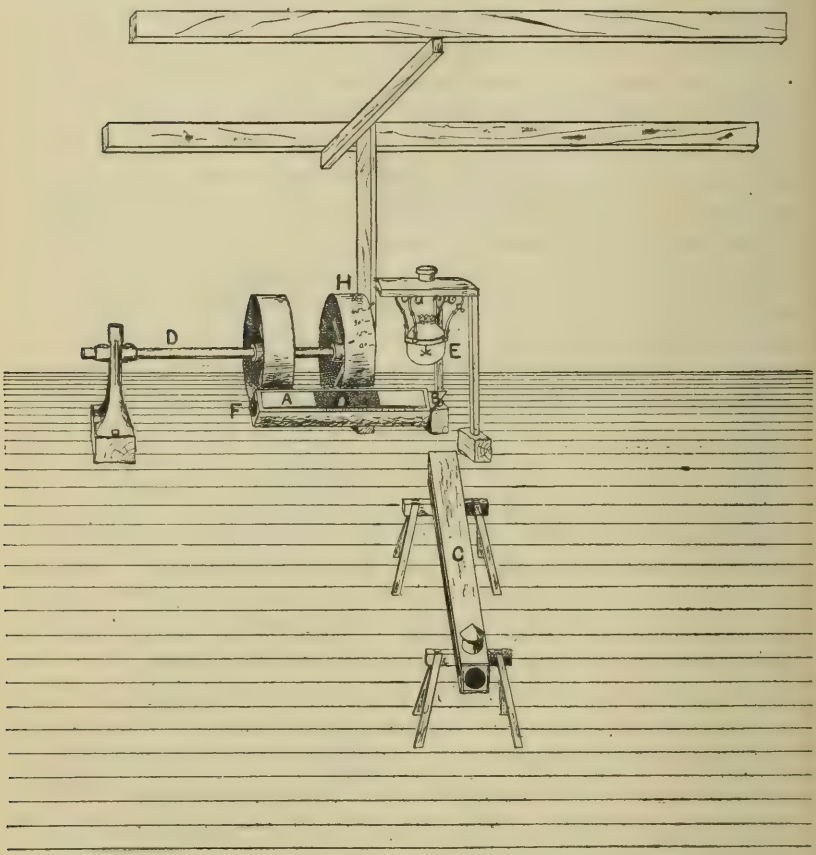

FIG. 144.

variations of the temperatures and anemometer readings in tests with the steam radiator in the box, with the corresponding ones in which the lamps were in the box. Where several lamp tests were made under nearly the same conditions, a single radiator test was made, and the proper corrections applied in reducing the corresponding heat for the lamp tests. The method of

making these corrections and details of the experiments will be given later. The arrangements of the currents of air in the testing box should not be looked at as a copy of the currents in a car. They are necessarily introduced to measure the heat, and indicate that the ventilator may be made to take away a great portion of the same.

To measure the candle power at various angles under the

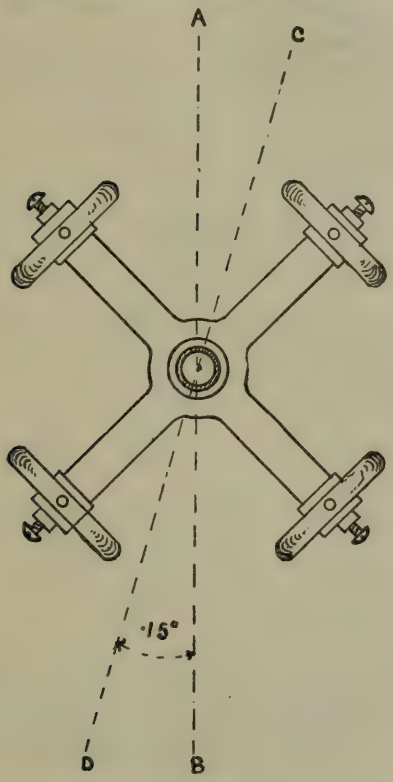

FIG. 145.

lamp, a rotating photometer, devised by Dr. Geyer, was adopted. This is represented in Fig. 144.

A is the photometer which is made to rotate about the shaft *D*. *B* is a mirror mounted at an angle of 45°. The lamp *E* is placed so that the flame center is on the center line of the shaft *D*. The candle power in a horizontal direction is first measured directly by means of a second photometer *C*, after which the photometer *A* is rotated so that it also measures the horizontal

candle power. The difference in the readings gives the loss due to the mirror. After reading the horizontal candle power by means of the rotary photometer, the candle powers at the various angles under the lamp are measured. The desired angles are marked on the pulley *H*. The standard candles for the rotating photometer are placed on a support, fastened on a special piece that is held against the end of the photometer at *F*. They are lifted from the support in order to weigh them. The candles used in the photometer *C* remain on a pair of candle balances. The results of the measurements by means of this photometer given in Tables III., IV., V., and VI. show that the average spherical candle power below a horizontal plane is in all cases nearly equal to that at 45°.

TABLE III.

CANDLE POWER AT VARIOUS ANGLES, GAS LAMP, TEST 24.

Time P. M.	Candle power corrected for mirror and rate of burning of candle.						
	Horizontal.	15°	30°	45°	60°	75°	Vertical.
10.30	39.6			34.9	34.3	26.4	25.1
11.00	37.2	37.2	33.2	35.9	35.9	23.9	22.6
Midnight.							
12.00	36.1	36.1	33.4				
12.25	37.7	37.7	32.5	33.8	35.1	26.0	26.0
Sum	150.6	111.0	99.1	104.6	105.3	76.3	73.7
Average	37.7	37.0	33.0	34.9	35.1	25.4	24.6

Average of readings for all positions below a horizontal plane = 32.5.
Average spherical candle power below a horizontal plane = 34.7.
Ratio of the spherical candle power to candle power at 45° = .99.
" " candle power in horizontal direction to candle-power at 45° = 1.08.

In test No. 8 the relative candle power at 60° and 45° was found to be $\frac{C.P. \text{ at } 60^\circ}{C.P. \text{ at } 45^\circ} = \frac{31.4}{32.5} = .97$* whereas in the above test the corresponding ratio is 1.01. The difference between these quantities is probably due to the fact that the lamp was placed in a slightly different position in regard to the photometer. The positions of the lamp are shown in Fig. 145.

* The details of this test are as follows :
Candle power at 45° taken over ¾ hour interval, mean of 5 observations = 32.4
" " " 60° after shifting photometer, " " 7 " = 31.4
" " " 45° photom. in original position, " " 5 " = 32.6

TABLE IV.

CANDLE POWER AT VARIOUS ANGLES, ARGAND OIL LAMP, TEST 26.

Time A.M.	Candle power corrected for mirror and rate of burning of candles.						
	Horizontal.	15°	30°	45°	60°	75°	Vertical.
3.00	23.1	18.9	18.9	16.8	10.5	4.9	7.0
3.50	18.2	16.8	15.4	12.6	8.4	4.2	5.6
4.20	19.6	16.8	15.4	11.2	8.4	3.5	5.6
Sum	60.9	52.5	49.7	40.6	27.3	12.6	18.2
Average	20.3	17.5	16.6	13.5	9.1	4.2	6.1

Average of readings for all positions below the horizontal plane.... = 12.5.
Average spherical candle power below a horizontal plane..... = 13.1.
Ratio of spherical candle power to candle power at 45° ..... = .97.
Ratio of candle power in horizontal direction to candle power at 45° = 1.50.

TABLE V.

CANDLE POWER AT VARIOUS ANGLES, ARGAND OIL LAMP, TEST 31.

Time P.M.	Candle power corrected for mirror and rate of burning of candles.						
	Horizontal.	15°	30°	45°	60°	75°	Vertical.
9.25	26.0	24.7	20.6	19.2	9.6	4.1	6.2
10.30	24.5	24.5	21.9	16.8	9.0	4.5	6.4
10.55	25.5	25.5	22.8	18.1	9.4	4.7	6.0
Sum	76.0	74.7	65.3	54.1	28.0	13.3	18.6
Average	25.3	24.9	21.8	18.0	9.3	4.4	6.2

Average of readings for all positions below the horizontal plane.... = 15.7.
Average spherical candle power below a horizontal plane ..... = 17.1.
Ratio of spherical candle power to candle power at 45°..... = .95.
Ratio of candle power in horizontal position to candle power at 45° = 1.41.

Candle power at angles above the lamp.

	Horizontal.	15° above =	30° above =	45° above =
C.P.	25.5	24.1	20.1	5.4

The candle power readings given in Tables IV. and V. are for one flame, furnished with a white porcelain shade as in car practice. To obtain candle power of lamp with two burners, multiply the results by 2. A supplementary test was made on an argand burner with a slightly larger spreader than those furnished with the car lamp, and having no shade. This test was made by measuring the candle power directly without the use of a mirror. The ratio of candle power at 60° and 45° was found to be 1.40.

TABLE VI.

CANDLE POWER AT VARIOUS ANGLES, FLAT FLAME OIL LAMP, TEST 27.

Time A.M.	Candle power corrected for mirror and rate of burning of candles.						
	Horizontal.	15°	30°	45°	60°	75°	Vertical.
4.45	11.0	11.7	11.7	8.3	6.2	4.1	5.5
5.09	11.0	11.0	10.4	8.3	4.8	4.5	4.8
5.15	10.4	10.4	9.7	7.8	4.8	4.8	5.5
Sum	32.4	33.1	31.8	24.4	15.8	13.4	15.8
Average	10.8	11.0	10.6	8.1	5.3	4.5	5 3

Average of readings for all positions below the horizontal plane..... = 7.9.
Average spherical candle power below a horizontal plane ..... = 8.3.
Ratio of spherical candle power and candle power at 45°..... = 1.02.
Ratio of candle power in horizontal direction to candle power at 45°.. = 1.33.
The flame was placed at an angle of 45° to the plane in which the candle power was measured.

In the tests of candle power by means of the rotating photometer, as given in Table III., the gas lamp was mounted so that the candle power was measured in the plane AB (Fig. 145). In a previous test (No. 8) to determine the relative candle power at the angles of 45° and 60° below the horizontal, by shifting the photometer, shown in Fig. 142, and in all the tests in which the heat generated by the lamp was determined, the candle power was measured in the plane CD. Fig. 145 represents the positions of the gas flames in looking downward on them.

The method of deducing the average spherical candle power below a horizontal plane, and of allowing for the light cut off by the oil wells and lamp attachments, is given in the appendix.

MEASUREMENT OF CANDLE POWER.

A Bunsen photometer was employed. The standard candles were purchased from the American Meter Company. These were compared with a "Sugg" standard candle and found to agree within 1%, which is less than the probable error of observation in candle-power measurements. For details of the comparative tests see Table VII.

TABLE VII.

COMPARISON OF CANDLE POWER OF "SUGG" STANDARD CANDLES AND THE STANDARD CANDLES OF THE AMERICAN METER CO.

Number of test.	Set of American Meter Co.'s candles.	Time to burn 10 grains of candle in minutes and seconds.		Ratio of actual intensity of American Meter Co.'s candle power to unity.	Candle power of candles for readings of photometer scales, American Meter Co.'s candles taken as standard.		Candle power of Sugg candle calculated from rate of burning.
		American Meter Co.	Sugg.		Actual.	Corrected for ratio of burning of American Meter Co.'s candle.	
1	2	3	4	5	6	7	8
1	A	2.54	2.37	.862	1.10	.95	.96
2	"	2.31	2.47	.993	.90	.89	.90
3	"	2.38½	2.47	.946	.95	.90	.90
4	"	2.42	2.42¾	.926	1.00	.93	.92
5	"	2.34½	2.37½	.971	.98	.96	.95
6	B	2.56½	2.40½	.850	1.10	.93	.93
7	"	2.54	2.32	.862	1.14	.98	.99
8	"	2.46	2.44½	.904	.95	.86	.91
9	"	2.39	2.24	.943	1.05	.99	1.04
10	"	2.45	2.31	.909	1.08	.99	.99
11	"	2.41	2.28	.932	1.10	1.02	1.01
Average						0.945	0.954

The candles therefore agreed with each other to within one per cent., which is less than the probable error in observation. Two flames were burned in each set of candles. The photometer scale was graduated for one candle, so that the readings should be multiplied by two to give the candle power developed in the test. This is not done, however, because the readings, as they now stand, give the average candle power for the candle.

Special tests were made to determine the effect of a spark on the ends of the candle wicks. These indicated that if the spark is a small one and does not alter the whiteness of the flame, the candle power, when corrected for the rate at which the wax is burned, is the same as for a candle in which the spark is completely removed. If the spark becomes large enough, however, to cause the flame to appear yellow, the candle power per grain of wax burned will be less than that given by a candle with no spark. The amount of falling off of candle power due to this cause may be as high as 15%.

In the candle-power measurements taken during the tests for

the heat given off by the lamps, the photometer was set at an angle of 45°. This was found to be about an average of the candle power measured below a horizontal plane passing through the flame center. See Tables III. to VI. In the heat tests, therefore, the candles were at an angle of 45° with the center line of the photometer. In placing the candles in their positions the measurements were taken from the center of the flames.

To prove that the candle-power readings taken with the candles at an angle were correct, special tests were made by Prof. Geyer. In these tests he employed the rotating photometer already described and shown in Fig. 144. The candles were placed in the positions which the lamp occupies in Fig. 144. A miniature electric lamp, which was regulated so that the light given off was the same color as that produced by the candles, was mounted in the rotating photometer. This lamp was preserved at a constant candle power. The slide in the photometer was set correctly for the horizontal candle power and the photometer revolved quickly to the position of 45°, when the slide was set over again. A number of such experiments proved that the difference in the candle power of the candles at 45° and in a horizontal direction was less than 1%.*

Two candles were used in measuring the candle powers of the lamps. These were set 100 inches from the lamp. The rate of burning of the wax was determined by noting, by means of a stop-watch, the time required to burn a given number of grains.

The candle powers of the argand oil flames and of the gas flames were measured throughout the heat tests without turning the lamp about its axis. In the argand oil flame care was exercised in adjusting the wick, so that the flame on the side toward the photometer was of the average height. The gas lamp was set at an angle that was found by previous tests by Dr. Geyer to be the one in which the average candle power was developed. It was concluded by Dr. Geyer that this candle power varied but little throughout the entire circle, so that any error involved by not turning the lamp at various angles in each of the tests was but a small one. The flat-flame oil lamp was revolved about its vertical axis through angles of 45°, so that every candle-power reading represents an average of eight positions.

* For details of these experiments see *The Stevens Indicator*, October, 1892.

TABLE VIII.

AVERAGE AND TOTAL RESULTS OBSERVED IN HEAT MEASUREMENTS.

Number of test.	Class of lamp.	Date of making test.	Duration of test in hours.	Velocity of air over car roof in miles per hour.	Number of flames burning.	Total candle power.	Cubic feet of gas burned per hour or pounds of oil per hour.	Barometer reading in inches of mercury.	Temperature of air in degrees Fahr.					Reading of thermometer placed near lamp and subjected to radiant heat in degrees Fahr.			Time required for anemometer to register 100 feet in seconds.		Volume of air passing through pipes per cu. ft. per second, determined by tests given in Table V.	
									Entering 12″ pipe.		Leaving 10″ pipe.	Leaving ventilator.	External air near testing box.	Roof 8½″ from center line of lamps.	Roof 12″ from center line of lamps.	Side of box at angle of 45°, and 22″ from flame.	In 12″ pipe.	In 10″ pipe.	In 12″ pipe.	In 10″ pipe.
									Dry bulb.	Wet bulb.										
1		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3	Gas.	July 27	3.0	10	4	33.0	.....	29.85	91.5	79.5	118.0	...	93.7	137	127	106	63.8	92.3	.....	1.220
4	"	" 27	3.0	0	4	33.9	.....	29.86	88.6	77.8	134.0	224	93.9	169	152	106	53.5	53.9	1.525	1.440
5	Oil arg. burner	" 28	2.2	40	2	33.2	.....	29.89	93.8	82.7	121.6	...	96.2	149	140	110	59.7	89 0	.....	1.238
6	" "	" 29	3.0	0	2	33.9	.....	29.92	86.5	78.0	132.7	301	92.2	174	147	104	55.3	54.5	1.510	1.430
7	" "	" 29	3.0	40	2	31.8	.....	29.92	87.6	78.5	118.5	...	90.1	151	135	101	61.4	85.4	.....	1.256
9	Gas.	Aug. 4	2.0	0	4	31.9	3.27 cu. ft.	29.84	85.4	77.0	142.4	...	87.7	...	...	99	86.2	....	1.133	.....
10	"	" 4	3.3	0	4	32.3	3.27 "	29.84	84.2	76.2	142.4	...	86.7	...	...	98	86.2	...	1.133	.....
11	Oil arg. burner	" 5	1.5	0	2	33.3	.....	29.84	83.1	76.2	159.8	...	85.6	...	...	108	66.3	....	1.293	.....
12	" "	" 5	4.5	0	2	32.2	.333 lbs.	29.84	81.7	74.0	158.1	...	84.5	...	...	104	65.2	....	1.306	.....
21	" "	" 25	2.0	40	2	33.5	.344 "	29.69	84.3	78.6	112.3	...	85.7	...	...	101	81.4	....	.....	1.276
28	Oil flat flame.	Sept. 13	2.7	0	2	....	.146 "	29.70	79.0	71.5	111.0	...	81.0	...	...	...	62.4	....	1.355	.....

NOTE.—In tests 9 to 12, and in test 28, a special cover was placed over the testing box so that all the air passing through the 12 inch pipe passed also through the 10 inch pipe. These tests measure directly the total heat of combustion of the gas and oil. In all the other tests the apparatus was arranged as shown in Fig. 142.

TABLE IX.

SPECIAL TESTS WITH A STEAM RADIATOR IN TESTING BOX TO DETERMINE THE HEAT CORRESPONDING TO GIVEN ANEMOMETER READINGS AND CHANGES OF TEMPERATURE.

Number of test.	Date of making test.	Duration of test in hours.	Temperature of air in degrees Fahr.				Barometer in inches of mercury.	Pressure of steam in radiator in lbs. per sq. in. above atmosphere.	Temperature in degrees Fahr.		Weight of steam condensed per hour in lbs.	Time for anemometer to register 100 ft. in seconds.		Volume of air in cu. ft. per second, calculated from the heat given up by the steam.	
			Entering 12″ pipe.		Leaving 10″ pipe.	External air near testing box.			Superheated steam entering radiator.	Condensed steam leaving radiator.		In 12″ pipe.	In 10″ pipe.	12″ pipe.	10″ pipe.
			Dry bulb.	Wet bulb.											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15	August 12	1.7	80.5	72.0	155.8	84.5	29.82	19.1	292.4	234.0	6.32	65.5	56.4	1.302	1.484
16	" 12	1.2	81.5	72.5	139.5	85.2	29.81	.8	261.5	182.4	4.05	86.2	67.8	1.133	1.254
17	" 24	2.0	81.5	72.5	124.2	86.1	30.04	5.9	269.4	137.4	3.10	71.0	55.2	1.232	1.329
18	" 24	1.5	81.5	73.5	133.4	87.2	30.02	13.1	301.0	149.0	4.00	67.8	54.2	1.307	1.432
19	" 25	1.7	81.5	77.4	117.5	84.7	29.51	4.3	267.1	119.1	2.45	104.9	86.5	1.175	1.252

DETAILS OF EXPERIMENTS.

The average and total results obtained in the heat measurements with the lamps burning in the testing box are given in Table VIII. Table IX. gives the tests with the steam radiator in the testing box. All the lamp tests were necessarily made during the night, as there was no means of darkening the room in which the apparatus was placed.

In order to insure average railroad conditions in the trimming of the lamps, an expert lamp man was employed during several evenings to regulate the flames.

It was found that there was a great difference between the candle power of the lamps as ordinarily run in car service, and the maximum candle power that could be developed for a short time. If the wick is turned up high enough, the candle power of a single wick at 45° may reach 30, but it will quickly fall to a lower figure.

The height of flame to produce 16 candle power is 1⅝ inches above the wick. This is an average of a great number of settings made by the expert lamp man, who trimmed the wicks between every few settings, three nights being devoted to this portion of the work. In order to further verify the fact that 16 candle power is an average for good car practice, the heights of flames in lamps in railroad service was observed, and it was found to be less than 1⅝ inches. By special adjustment of the wick, however, the flame may be made to burn at a higher candle power than 16. In the test which was the most favorable the candle power at the start was 26, and after running six hours it was 22. At the beginning of this test the lamp did not smoke, but after running one hour it commenced to smoke slightly, and continued to do so for three hours. The flame in this case was worked over for two hours before the beginning of the test, the wick being pressed down at the points which produced smoking. The wick was turned up one-eighth of an inch, which was also the height for 16 candle power, as trimmed and adjusted by the expert lamp man. If the wick is turned higher than one-eight of an inch the candle power will rapidly fall off on account of the wick becoming coated over with a hard crust. If turned up high enough to obtain the maximum flame, the candle power at 45° will fall from 30 to 18 in about ten minutes.

The flat flame lamps were also set by the expert car man, and the height of flame thus obtained, which was $1\frac{3}{8}$ inches above the wick guard, compared with that in car practice. In this case, as in the argand lamp, the flame was found to be slightly larger than that employed in average car service.

The duration of the tests given in Tables VIII. and IX. is that over which the data is averaged. In all of the tests the apparatus was run some time before the data used in obtaining the average results was recorded. This was necessary in order to allow the testing box to become thoroughly hot. It was also

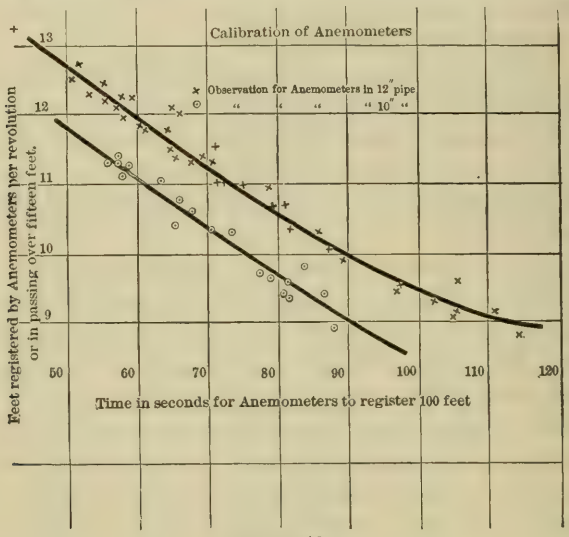

FIG. 146.

difficult in some cases to obtain the desired set of conditions in regard to the velocity of air passing through the box, etc. In many cases the record was not taken until the apparatus had been in operation four hours. The average time required in starting the tests was about two and a half hours.

The reading of thermometers placed near the lamps and subjected to radiation are given in columns 15, 16, 17 of Table VIII. These were placed so that their bulbs protruded one half way through the car ceiling, and through the sides of the testing-box.

In order to allow for differences in the velocities of air passing through the testing box, in the lamp and radiator tests, the following method was employed.

The anemometers were standardized by placing them on the end of a revolving arm and noting their readings. This arm was made of such a length that the distance traveled over per revolution was fifteen feet. Calibrations were made throughout the entire range of velocities that the anemometers ran at during

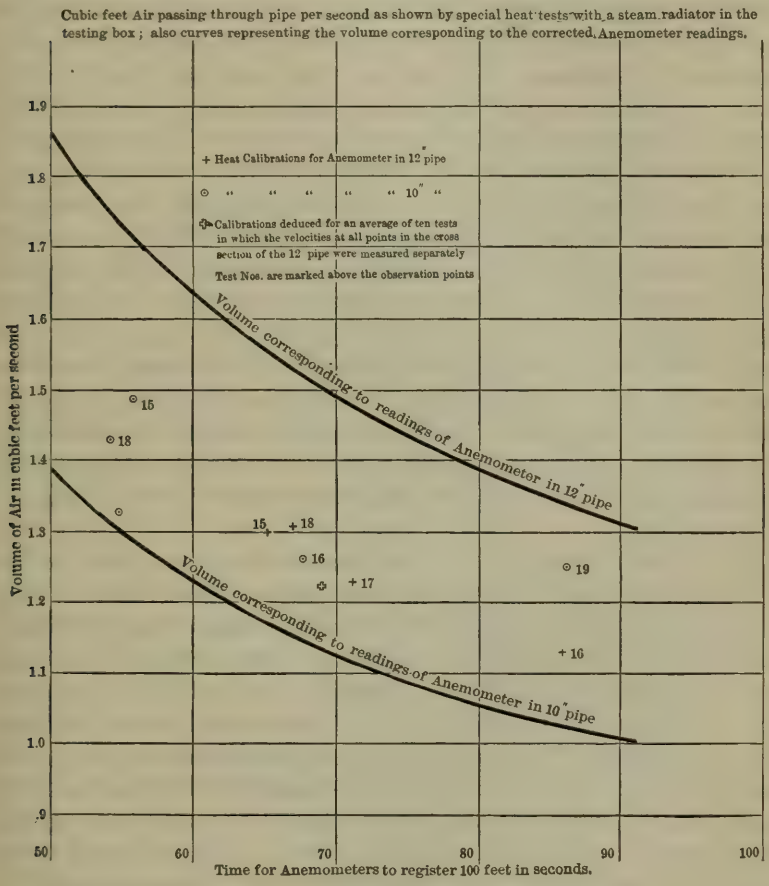
Cubic feet Air passing through pipe per second as shown by special heat tests with a steam radiator in the testing box; also curves representing the volume corresponding to the corrected Anemometer readings.
+ Heat Calibrations for Anemometer in 12" pipe
⊙ " " " " " 10" "
Calibrations deduced for an average of ten tests in which the velocities at all points in the cross section of the 12" pipe were measured separately
Test Nos. are marked above the observation points
Volume corresponding to readings of Anemometer in 12" pipe
Volume corresponding to readings of Anemometer in 10" pipe
Volume of Air in cubic feet per second
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
50
60
70
80
90
100
Time for Anemometers to register 100 feet in seconds.

FIG. 147.

the heat tests. The results of the calibrations are indicated in Fig. 146.

The anemometers when used in the heat tests were moved about in the center portions of the pipes conducting the air.

In Fig. 147 the curves are given which show the number of cubic feet of air that would pass through the pipes per second

provided the average velocity was that indicated by the anemometer after the proper corrections, as determined by the curves given in Fig. 146, are applied.

The crosses and dots with circles around them in Fig. 147 represent the radiator calibrations of the anemometers. These calibrations give the volume of air that would have to pass through the pipes per second to absorb the heat given up by the radiator, with the range of temperature that this amount of heat is observed to produce. To correct these volumes of air for the slight differences in the anemometer readings between the radiator and corresponding lamp tests, we measure the variations in the volumes corresponding to the anemometer velocities, as shown by the curves given in the figure, and apply these corrections to the volumes indicated by the radiator tests. That this method is a correct one, through a small range, is shown by the radiator calibrations of the anemometer in the 12-inch pipe. These calibrations are indicated by the curves in the figure, and it is seen that a curve passing through them will be about parallel to the curve which represents the volumes corresponding to the anemometer velocities. The fact that the curves just mentioned are parallel also, goes to show that the effect of difference in radiation of heat from the testing box was small enough to be disregarded.

As a general check on the air measurements a special series of tests were made in which the anemometer was revolved slowly in circles of different diameters about the center line of the 12-inch pipe. The velocity was first taken at the center, then in a circle of small radius about the center, next in a still larger circle, and so on until the anemometer was moved around against the pipe itself. The velocities obtained in this way were considered to act over the annular area covered by the blades of the anemometer during its circular travel, and the weight of air for the annulus was thus determined. The sum of the weights for all the movements of the anemometer gave the total weight of air passing through the tube. A mean of ten experiments made in this way gave the point so marked in Fig. 147. This point is practically in line with those obtained by the radiator tests.

A curve cannot be passed through the radiator-test calibration for the anemometer in the 10-inch pipe. These calibrations are indicated in the figure by the dots inclosed in circles. The reason for this is that the great variation in temperature, and,

therefore, in the density of the air in the 10-inch pipe, caused the rate of the anemometer to be materially different from that which it had at ordinary temperatures. In the case of the anemometer in the 12-inch pipe, however, the temperature of the air was about the same as that in which it was calibrated by revolving it at the end of a lever arm, consequently the results obtained by the radiator tests follow a definite law, and the volume of air as determined in the ten tests where the anemometer was moved in concentric circles practically agrees, as we have already stated, with the results of the radiator tests.

In making the tests of the anemometers by revolving them at the end of a lever arm, great precaution was taken to prevent a draught from affecting the readings. Partitions were placed so that they tended to prevent a circular movement of the air about the room. The direction of revolution was also reversed after each test, so that any accidental draught in a given direction would be eliminated. Two observers noted the readings of the anemometers at each revolution, and a third recorded the time by means of a stop-watch. The duration of the tests was from five to fifteen minutes. After completeing the tests the differences for each revolution were taken, to insure that all the revolutions had been recorded, and the total number of revolutions in the given time were then counted.

The results given in these tests, as represented in Fig. 146, appear somewhat irregular, on account of a certain amount of draught that could not be entirely eliminated from the air in the room, which caused the readings of the anemometer when revolved in one direction to be greater than when revolved in the reverse way. This irregularity does not, however, affect the accuracy of the average results indicated by the curves shown in the figure. To plot the curves, the center of gravity of several groups of experiments were taken and the curve passed through the points thus obtained.

The record during one of the lamp tests is given in Table X., and the record for the corresponding radiator test in Table XI.

TABLE X.

TEST NO. 11.—OIL LAMPS, ARGAND BURNERS.

Record taken below Platform.									Record taken on Platform.							
Time.	Time for anemometer to register 100 ft. in 12″ pipe in seconds.	Temp. of air entering 12″ pipe in deg. Fahr.		Barometer in inches of mercury.	Photometer.				Time.	Temperature of air in degrees Fahrenheit.						
		Dry bulb.	Wet bulb.		Time to burn 10 grains of candle in sec.	Correction for rate of burning.	Candle power by photometer scale.	Corrected candle power.		Outside air near testing box.	Side of box at angle of 45° and 22″ from flame.	Air leaving 10″ pipe measured by five thermometers.				
												Centre.	Front.	Back.	Right.	Left.
12.00	.....	.....	.....	.....	155	.968	17	16.5	12.30	85.8	106.75	158	156.5	159	158.5	159
12.25	68.25	83	76.5	29.84	.....	.....	.....	.....	12.45	85.8	106.75	158	157	159	157	158
12.30	.....	.....	.....	.....	155.5	.964	17	16.4	12.55	85.7	107	159	158	160	159	159
12.45	67	83.5	76.5	29.84	.....	.....	.....	.....	1.15	85.7	107.5	160.5	158.5	160	160.5	160.5
12.55	71.5	83	76.5	29.84	.....	.....	.....	.....	1.25	85.5	107.75	160.5	159	161	161	160.5
1.00	.....	.....	.....	.....	151	.993	16.5	16.4	1.45	85.5	108.75	161	160	162	162	162
1.15	68.75	83	76	29.84	.....	.....	.....	.....	1.55	85.4	109.5	162	160	162	162	162
1.25	64	83	76	29.84	.....	.....	.....	.....	Average	85.6	107.7	159.9	158.4	160.4	160	160.1
1.30	.....	.....	.....	.....	156.25	.960	18	17.3								
1.45	63.75	83	76	29.84	.....	.....	.....	.....								
1.55	61	83	76	29.84	.....	.....	.....	.....								
Average	66.3	83.1	76.2	29.84	.....	.....	.....	.....								

Final average for air in 10″ pipe = 159.8° Fahr.

TABLE XI.

SPECIAL TEST (NO. 15) WITH RADIATOR IN BOX, AUGUST 12, 1892.

Record taken below Platform.								Record taken on Platform.											
	Temperature of air entering 12″ pipe in degrees Fahr.				Weight of steam pail in lbs. and ounces.				Temperature of air leaving 10″ pipe.										
Time.	Dry bulb.	Wet bulb.	Barometer in inches of mercury.	Time for anemometer to record 100 ft. in 12″ pipe in seconds.	Initial.	Final.	Difference.	Time.	Center.	Front.	Left.	Right.	Back.	Average.	Time for anemometer to register 100 ft. in 10″ pipe in seconds.	Pressure of steam in radiator in lbs. per sq. in. above atmosphere.	Temperature of superheated steam entering radiator in degrees Fahr.	Temperature of water condensed from steam leaving radiator in degrees Fahr.	Temperature of external air, degrees Fahr.
P.M.								P.M.											
10.30	77.	69.	29.82	63.5	21 — 4.	.....	.....	10.30	153.	153.	152.6	154.4	150.	152.6	57.75	19.25	303.	238	82.9
10.40	79.5	71.5	29.82	65.5	.....	.....	.....	10.45	154.	154.	154.4	156.2	154.	154.5	61.75	19.25	312.	237	83.6
10.50	80.	72.	29.82	65.	.....	.....	.....	11.00	156.	155.	155.3	157.1	155.	155.7	54.	19.0	303.	234	84.3
11.00	80.5	72.5	29.82	67.	19 — 4 75	24 — 6.5	3—2.5	11.15	156.	156.	156.2	158.	156.	156.4	56.	19.25	299.	234	84.7
11.10	81.	72.5	29.82	65.5	.....	.....	.....	11.30	156.	156.	155.3	157.1	155.	155.9	56.5	17.75	289.	229	85.
11.20	81.	72.5	29.82	64.	.....	.....	.....	11.45	157.	157.	157.1	158.9	157.	157.4	55.	20.0	284.	235	85.1
11.30	81.	72.5	29.82	64.50	22 — 12.25	22 — 7.5	3—2.75	12.00	156.5	156.5	156.2	158.	156.5	156.7	54.75	19.75	276.	234	85.2
11.40	81.5	72.5	29.82	67.	.....	.....	.....	12.15	157.	157.	157.1	158.9	156.	157.2	55.5	18.25	273.	231	85.3
11.50	81.5	72.5	29.82	66.5	.....	.....	.....	.....	....	....	.....	.....	....	....	.....	.....	.....	.....	.....
12.00	81.5	72.5	29.82	.....	21 — 4.75	25 — 14.5	3—2.25	.....	....	....	.....	.....	....	.....	.....	.....	.....	.....	.....
12.10	81.5	72.5	29.82	66.	.....	22 — 14.25	1—9.5	.....	....	....	.....	.....	....	.....	.....	.....	.....	.....	.....
12.15	.....	.....	.....	.....	.....	.....	.....	.....	....	....	.....	.....	....	.....	.....	.....	.....	.....	.....
Aver.	80.5	72.0	29.82	65.5	.....	.....	11—1.	.....	....	....	.....	.....	....	155.8	56.4	19.06	292.4	234	84.5

The following are the details of the calculations for this particular lamp test.

We first determine the volume of air that flows through the testing box in the special test with the steam radiator; we have, from Table XI.:

Weight of steam condensed per hour in pounds	6.32
Amount that steam entering radiator is superheated in degrees Fahr.	38.4*
Total heat of steam corresponding to observed steam pressure in B. T. U.	1192
Temperature of condensed steam leaving radiator	234
The B. T. U. given up by the steam per hour will be $6.32\ (.48 \times 38.4 + 1192 - 234) = 6171$	
Corresponding B. T. U. per second	1.714
Increase of temperature of air in passing through testing box in degrees Fahr.	75.3
Weight of air per second in pounds $= 1.714 \div (.238 \times 75.3) =$	.0956
Volume of air in cubic feet per pound at temperature of entrance to 12-inch pipe	13.605
Volume of air in cubic feet entering 12-inch pipe per second $= .0956 \times 13.605$	1.301

This value is represented by the cross marked 15 in Fig. 147.

In the lamp tests corresponding to this radiator test, the record of which is given in Table X., the temperature of the exit air and time required by the anemometer to register 100 feet were 159.8° and 66.3 seconds. For the radiator test the quantities are 155.8° and 65.5 seconds. To correct for the difference in the anemometer readings we make use of the curve for the volume of air registered by the anemometer used in the 12-inch pipe given in Fig. 147. From this curve we find that the difference in the quantities of air for the readings is .009 cubic feet per second; the corrected volume of air in cubic feet per second for the reading of 65.5 seconds is, therefore, $1.301 - .009 = 1.292$. The weight of air passing through the testing box in pounds per second is therefore $\frac{1.292}{13.671} = .0945$.

The range of temperature is 76.7° and the B. T. U. imparted to the air per second is $.0945 \times .238 \times 76.7 = 1.726$, and the corresponding heat per hour $1726 \times 60 = 6214$ B. T. U. This heat is developed by the lamp when burning at 33.3 candle power. The heat per 32 candle power per hour will therefore be:

* The reading of the thermometer corresponding to saturated steam was determined experimentally and a table compiled, which is employed in obtaining the above amount of superheating. This method eliminates any error in the thermometer.

$$\frac{6214 \times 32}{33.3} = 5971 \text{ B. T. U.},$$

which is the figure given in Table I.

A wet-bulb thermometer was read during all the tests. This indicated that the percentage of saturation of the air varied from 53% to 72% for all the lamp tests. The degree of saturation for the radiator tests is between 63% and 72%. In the calculations we have assumed a constant degree of saturation as the amount of error by so doing as a maximum less than 1% of the total results obtained. In the tests for the total heat per pound of oil and per cubic foot of gas the correction for the moisture contained in the oil is less than $\frac{1}{2}$%. The effect of superheating the vapor of water in the products of combustion that is produced by the hydrogen in the oil or gas is less than $\frac{1}{5}$% of the total heat involved. The degree of accuracy in the tests does not warrant the application of the small corrections given above, and they have therefore not been made.

COMPARISON OF THE HEATS OF COMBUSTION DETERMINED BY MEANS OF THE APPARATUS HEREIN DESCRIBED, WITH THOSE CALCULATED FROM THE ANALYSES OF THE OIL AND GAS.

Three analyses were made by Dr. Stillman on the oil used in the lamps; these agree very well with each other, and show that it contains 13.2% of hydrogen and 83.3% of carbon, the remaining ingredients being oxygen, nitrogen, etc. This oil is called "Mineral Seal" by the trade. It has a density of 40° Beaume, which corresponds to a specific gravity of .83. The flash test is 266° Fahr. and the fire test 311° Fahr. It is a pure mineral oil.

The calculated heat of oil per pound is

Hydrogen = 52,370 × .132 = 6,913 B. T. U.
Carbon = 14,500 × .833 = 12,079 " " "
Total heat of combustion, 18,992.

The average result obtained by the two experiments given in Table I. is 18,790, which is 1.1% lower than the value calculated from the analysis.

The heating power per pound of hydrogen employed above is

that given by Favre and Silberman after the heat contained in the water vapor is deducted.*

In experiments on the heat of combustion of petroleum oils from Russia, H. St. Claire de Ville, the heat of combustion by experiment was from 1.7% to 3.5% lower than the calculated value.†

The results obtained for the petroleum oil are therefore in line with his experiments.

The analysis of the gas is not as precise as the oil analysis, for the hydrocarbons, with the exception of the marsh gas present, are determined as a whole. An average of two analyses gives the following per cents. by volume :

Hydrocarbons, with the exception of marsh gas	38 1
Carbon monoxide	0.5
Marsh gas	57.7
Hydrogen	3.4
Nitrogen	0.3

If the 38.1% of hydrocarbons are assumed to be divided into benzole vapor = 10%, propylene = 10%, and olefiant gas = 18.1%, the theoretical heat of combustion per cubic foot at the temperature at which the experiments were made is 1,337 B. T. U. If the division is made so that the benzole vapor = 5%, propylene = 10%, and olefiant gas 23.1%, the total heat of combustion per cubic foot is 1,231 B. T. U.

In calculating the theoretical heat of combustion, the effect of the latent heat of the water vapor has been allowed for. The heats of combustion of the hydrocarbons employed are those determined experimentally by Julius Thomsen.‡

The heats calculated from the analyses therefore fall in line with the experimental results for both the oil and gas.

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* Heating power of one pound of hydrogen, including latent heat of water vapor = 62,032 B. T. U.—*Annales de Chimie et de Physique*, 1852.

† *Comptes Rendus*, 1871, page 192.

‡ For the method of allowing for the water vapor present, and the transformation from the heats per molecule as given by Thomsen to British units, see *The Stevens Indicator*, Oct., 1892.

APPENDIX.

METHOD OF DEDUCING THE AVERAGE SPHERICAL CANDLE POWER.

The average spherical candle power below a horizontal plane, deduced from Tables III. to VI., corresponds to that which would be obtained if the candle power was measured over a great number of equal areas on the surface of the hemisphere, and an average was taken of all the measurements.

The readings of candle power given in the tables were taken in such a manner as to make them the mean values for all possible positions of the flame when revolved about a vertical axis through the flame centre. If the lamps cast no shadows, the spherical candle power is equal to the sum of the products of the candle powers given in the table, each multiplied by the area of its horizontal zone, divided by the area of the hemisphere.

To correct for the shadow cast by the oil wells and lamp attachments, we deduct from the sum of the products of the candle powers multiplied by the areas, the product of the area shaded by the oil well, etc., multiplied by the average candle power that would be produced over this area if the light was not intercepted.

This method is an approximate one, inasmuch as it assumes the light to emanate from a point, instead of being diffused by means of the white porcelain shade. There is a further approximation involved in allowing for the area illuminated at each of the candle powers given in the tables. On the whole, however, the method is as accurate as is required for the purpose for which it is employed, which is simply to show that in each lamp the candle power at an angle of 45° below a horizontal plane is about equal to the spherical candle power below a horizontal plane.

The portion of the area of the hemisphere cut off by the oil well and attachments in the "Argand Lamp" is 10.3% and of the "Flat Flame Lamp" 8.3%. These figures do not include the base of the burners, as the full effect of the shadow cast by them is included in the figures given in the tables. The greater portion of the shaded areas given above is included between the horizontal plane and one at 45°, so that the average candle power

cut off is considered to be an average for all positions over this range.

There is no correction for the shadows in the gas lamps, as the full effect of all the shadows cast is included in the figures given in Table III.

The method of performing the calculations is given in detail in Table XII.

TABLE XII.

CALCULATION OF SPHERICAL CANDLE POWER BELOW A HORIZONTAL PLANE.

Angle.	Area illuminated, that of the hemisphere being unity.	Candle powers from Tables III. to VI., multiplied by values given in Column 2.			
		Table III.	Table IV.	Table V.	Table VI.
1	2	3	4	5	6
Horizontal.	.130	4.901	2.639	3.289	1.404
15°	.252	9.324	4.410	6.275	2.772
30°	.226	7.458	3.752	4.927	2.396
45°	.185	6.456	2.498	3.330	1.498
66°	.131	4.598	1.192	1.218	.694
75°	.067	1.702	.281	.295	.302
Vertical.	.009	.221	.055	.056	.048
Sum or spherical C. P., neglecting shadows cast by oil wells.		34.660	14.827	19.390	9.114
Ave. C. P. between horizontal plane and one at 45°		.....	17.0	22.5	10.1
Portion of hemisphere covered by shadows cast by oil wells.		0	.103	.103	.083
Correction for shadows cast by oil wells.		0	1.751	2.317	.838
Corrected spherical candle power.		34.7	13.1	17.1	8.3
Ratio to candle power at 45°		.99	.97	.95	1.02

DISCUSSION.

Prof. R. H. Thurston.—I find many interesting points in this paper, and much valuable information to supplement the results of earlier investigations. The method of measurement of the quantities of air flowing, by the use of anemometers, would be liable, I should have thought, to sensible errors due to the variable rate of flow of the air-currents at different points in the stream; but I am inclined to think that Professor Jacobus has been able to secure good measures of flow and of temperature in this case. In our own laboratories we have, in the investigation of the effectiveness of radiators, found this to be a serious and fruitful source of uncertainty; but we have, of course, there dealt with currents of comparatively slow velocity and uncertain directions. It is interesting to observe that the conversion of the oil into gas increases its efficiency as an illuminant; that it is better to vaporize it by an extraneous source of heat than by its own heat of combustion. This difference in efficiency, if I read the figures aright, is about 50% in favor of the oil; as the percentage of the energy of the substance which appears as light is very minute.

These investigations of the "energy-cost" of light are assuming constantly greater importance in the eyes of engineers and of physicists, as it becomes recognized that the wastes are something enormous, and that ordinary lights only utilize a very minute fraction of the energy expended in their production. That this is the fact is shown by a large number of direct investigations, and that it should be so will be seen to be inevitable under usual conditions, when it is considered that the source of light is almost invariably, at present, either the combustion of some fuel or the incandescence of some solid heated to high temperature through the action of energy derived from fuel-combustion, originally. In the former case, the energy due to chemical action is disposed of as light and heat of every possible wave-length and intensity from end to end of the spectrum, and in large degree in invisible form. Even in the visible spectrum, as has long been known, and as Langley has so beautifully shown, energy of radiation and vision have no constant relation; but some portions of the spectrum expend 100,000 times as much energy as others in affecting the retina to equal extent.* Thus, "totally different optical effects are

* *Energy and Vision*, First Paper, National Academy of Sciences, Vol. V., 1888.

produced by the same amount of energy, according to the wave-length in which this energy is exhibited"; and this energy is not equally distributed, even in the spectrum itself.

The eye is so differently affected that Langley gave up the use of the ordinary forms of photometer as inexact for his purpose. The eye is especially liable to be deceived as the rays become more obscure, and those from the violet end of the spectrum are especially uncertain; and all this notwithstanding the fact that the normal eye can perceive lights varying in intensity in the proportion 1,000,000,000,000,000 to 1.

Many investigations bearing upon this subject have been made in our laboratories at Cornell University, and it may interest those who have followed this discussion to learn a few of the facts revealed. Professors Nichols and Merritt have obtained some particularly interesting results, judged from the standpoint of the engineer. In this work it was found that photometric methods were not satisfactory; as "the candle power is rather a physiological than a physical unit," and the invisible as well as the visible spectrum and its energy at all points must be studied. Calorimetric methods must always be resorted to. Adopting methods known to be correct within one-fourth of one per cent., it was found that the absorption of light was only from 25% to 30% in the calorimeter; nor does the water in the calorimeter absorb all the dark heat, as was perhaps first shown by the researches of Tyndall. All corrections made, however, the light of a 16-candle-power Edison lamp was found to contain from one-half to about five per cent. of the energy of the whole spectrum distributed by it, as its candle power rose from one to thirty-eight.* Another series of observations by a different method gave a ratio of light-energy to candle power varying from 1.6 to 0.4 for 16-candle-power lamps, in rising from an actual candle power of less than one to about the rated power; the cost in energy decreasing with increasing E. M. F. and current, and with increasing intensity of light. What we have to do, in this direction, with the common illuminants is obviously to seek means of raising the intensity of the light to a permanent and maximum point of incandescence of the particles radiating that light. In these last experiments, we find the energy per candle power varying from 1.5 watts, at one-half, to 0.3 watts at 16 candle power. Dr. Julius Thomsen found

* *American Journal of Science*, Vol. XXXVII., March, 1889.

the energy of the candle-power from the oil-lamp to be about 2.5 watts, say one two-thousandth horse-power. Our observers also find the light from the gas flame to be of the same quality with that from the Edison lamp.* This means, I presume, equal temperatures of the carbon of which, in both cases, the flame is composed. In these cases we have seen that, as by Thomsen's determinations, only 2 per cent. of the radiant energy is light. Ninety-eight per cent. of our energy, and its cost in money, is wasted. Seven-eighths of the total energy is lost by convection.

The incandescence lamp is thus found much more efficient as a light-producer than the oil lamp, or even than gas; but it is still very wasteful. The arc lamp is a little better. The investigations of Mr. Nakano, an able young Japanese, in our laboratories, give a mean "hemispherical" efficiency of from seven to seventeen per cent., as the size of carbons is diminished from 0.8 to 0.25, rising from fifty per cent. more than the efficiency of the incandescent lamp, to three times that efficiency. The current was kept at about 9 amperes; the tension, at about 45 volts. Variation of current and voltage, so far as they occurred, made no sensible difference. Increasing intensity, however, here as in the other cases, increases efficiency.† These facts also lead to the conclusion that candle power is no measure of the light-producing energy, or of the luminosity, for any wide range of intensity; and it is, as remarked by Dr. Nichols, already "a wellnigh meaningless term" in arc-light photometry. In illustration of these facts, and as illustrating these variations in "efficiency," we may compare the figures given below, from Mr. Preece's address at the Bath Meeting of the British Association, 1888, with two lines added, from the above data.

Illuminant.	Watts per candle.	Gr. cal. per min. per candle.	Efficiency.
Tallow	124	1,770	.00203
Wax	94	1,340	.00268
Sperm	86	1,230	.00293
Mineral oil	80	1,143	.00315
Vegetable oil	57	815	.00442
Coal gas	68	971	.00317
Cannel gas	48	685	.00521
Incandescent lamp	5	72	.05
Arc lamp	2.5	35	.10

* Nichols and Franklin in *Proc. A. A. A. S.*, 1888.

† See *Trans. Am. Inst. E. Engrs.*, 1889, for Nakano's paper.

In the case of electricity, the final efficiency is reduced by the fact that, in the utilization of the heat-engine as a prime mover, a loss of from nine-tenths to seventy-five hundredths must be submitted to in the transformation of heat into power, as in all thermodynamic machines, and the figures given must, in such comparisons, be multiplied by, usually, not less than ten. It will be noted that, in every instance, so far as present experience goes, the incandescent substance, in all forms of commercially valuable light, is carbon. The variation of the brilliancy and the efficiency of the light is simply a function of the temperature to which it is possible to raise that incandescent carbon. The arc lamp owes its superiority to its high temperature, and to the fact that this, in turn, gives both higher efficiency in proportion of light to total radiant energy, and in higher value of the light given out. It approximates more nearly in quality to sunlight and daylight; but it is still far from the latter in value on both counts.

Lime, incandescent, as in the common lime-light of the oxy-hydrogen burner, is richer than either of the illuminants in the table; especially in the violet and other short wave-lengths, of which it gives twice as large proportion as the gas or incandescent lamp; while the small carbon arc-lamp is still whiter, and is superior in the same proportion to the lime light.*

Magnesium, however, seems to be the most remarkable and promising illuminant, as viewed from this standpoint. This singular metal was brought into use as long ago as 1865, or earlier, both in Great Britain and the United States, by the Magnesium Metal Co., and by the American Magnesium Co.; and it was sold in considerable quantities and in increasing amount until shut out by the introduction of the electric light. At that time I became much interested in the subject, and introduced several forms of lamp and of signal-light apparatus, using, in some cases, a "ribbon-lamp," which I patented at the time; in others, forms of powder-burning lamp, in which a mixture of magnesium powder and "blotting sand" was employed. It is still used for production of light, especially in the flash-powders used in photography by night. I am very much inclined to expect its rapid and extensive introduction for more general purposes, once its extraordinary properties and special value become recognized and when the costs of production are brought down, as I have no doubt will be

* *American Journal of Science*, August, 1889, Cornell University Contribution No. 5.

the fact, to a fraction of the present figures—about fifty cents an ounce—and which are vastly less than years ago, when I endeavored to introduce it.

Magnesium is now well known as a metal of remarkably low density (1.75), with atomic weight 24. A ribbon or powder of this metal burns rapidly and with high temperature and wonderful brilliancy, with higher efficiency as both a heat-producer and as a light-giver, than any other known substance. It is exceedingly plentiful in nature, serpentine containing 26% by weight, 37% of its volume, of the metal. Every cubic foot of sea-water holds in solution 1.34 ounces—0.6 cubic inch. It melts at a red heat, volatilizes and distils at a white heat, like zinc, and affords some promising alloys. It does not readily or rapidly oxidize, unless kept polished, a superficial coating of oxide protecting it, like that of nickel. It may be anticipated, I have no question, that it will in time come to be made by electrolysis, like aluminium.

Investigations in our laboratories, by Messrs. Nichols and Rogers, give some striking comparisons for present purposes.* It has long been known, as shown, for example, by Pickering in 1879, that its light approaches that of daylight more nearly than that of any other known artificial light, being peculiarly rich in the short wave-lengths and in the violet and other actinic rays. Its temperature of combustion is far above that of the candle flame (800° C.) and the gas flame (1,000° C.), and even the Bunsen gas-burner (1,200° C.) and air-blast flame (1,400° C.) only slightly exceed it, its temperature being reported by Nichols at 1,340° C., or 2,444° Fahr. This investigator shows, also, the probability that its light is not wholly due to incandescence, but, in part, to something like fluorescence by heating. Its net efficiency as a light-producer is, as an average of all determinations by various methods, above 0.135, and its heat of combustion about 6,000 calories per gr. Its solid ash gives it the further extraordinary advantage of making three-quarters of its total energy of combustion radiant energy. The thermal equivalent of one candle-power minute is 2.39 calories. Although burning at 1,350° C., its light is such as would correspond more nearly to 5,000° C. for ordinary simple incandescence.

Its light-giving power is thus fifty to sixty times that of gas per

* *American Journal of Science*, April, 1892.

unit of energy expended, and we can thus afford to pay fifty times as much for it for ordinary purposes, and much more than this even for the extraordinary uses to which it is peculiarly adapted. At $2.00 a thousand feet for gas, and $3.00 a kilogram, or $1.20 a pound, nearly, for the metal, their value would be about the same. Aluminium now costs less than a half-dollar to make; there seems no reason to question the possibility of magnesium falling to some such figure, given the demand in the market to justify its manufacture on an extensive scale. The fact that since two candle power of sunlight has higher value for purposes of vision than three of gas, illustrates the fact, also, that magnesium, which lies between these two values, will have correspondingly increased available light-power and value. Perhaps it would be safe to assume that it is as economical at 75 cents a pound as gas at one dollar a thousand. Its "luminescence" is higher proportionally than its incandescence, as compared with any other known illuminant.

But even the superiority of fifty or sixty to one of magnesium, in comparison with other illuminants, fades into insignificance beside that of the glow-worm and of the fire-fly, which have been shown by Langley to have an efficiency, as light-givers, of about 0.9975. This, after all, as I remarked in one of my president's addresses before the American Society of Mechanical Engineers, ten years ago, is the light to be sought as the "light of the future."* As I then remarked:

"I have sometimes said that the world is waiting for the appearance of great inventors, yet unknown, for whom it has in store honors and emoluments far exceeding all ever yet accorded to any one of their predecessors. The first is the man who is to show how, by the consumption of coal, we may directly produce electricity, and thus, perhaps, evade that now inevitable and enormous loss that comes of the utilization of energy in all heat engines driven by substances of variable volume. Our electrical engineers have this great step still to take, and are apparently not likely soon to gain the prize that will reward some genius yet to be born. The second of these greatest of inventors is he who will teach us the source of the beautiful soft-beaming light of the fire-fly and the glow-worm, and will show us how to produce this singular illuminant and to apply it with success practically and

* *Transactions American Society of Mechanical Engineers*, November, 1881.

commercially. This wonderful light, free from heat and from consequent loss of energy, is nature's substitute for the crude and extravagantly wasteful lights of which we have, through so many years, been foolishly boasting. The dynamo-electrical engineer has nearly solved this problem. Let us hope that it may be soon fully solved, and by one of those among our own colleagues who are now so earnestly working in this field, and that we may all live to see him steal the glow-worm's light and to see the approaching days of Vril predicted so long ago by Lord Lytton."

*Prof. Jacobus.**—I thank Professor Thurston for his kindly discussion of my paper; there are a few points in his remarks, however, which may be misleading to the casual observer, and I therefore call attention to them. It is difficult to draw general conclusions in regard to gas-light efficiency, because different methods of burning the gas produce different results. For example, the oil gas employed in the tests given in the paper gave only 5 candle power per cubic foot per hour when burned in a small argand flame such as is ordinarily employed for coal gas, whereas in a special form of regenerative lamp 15 candle power per cubic foot was obtained. The figures given in the paper are for a burner giving 10 candle power per cubic foot of gas per hour, so that by varying the burner the heat per candle power and the efficiency may be raised or lowered 50%.

The statement is made that the incandescent light is found much more efficient as a light producer than the oil lamp or even than gas. This is misleading, for the fact is that, starting from the coal pile, the amount of light generated will be about the same. This was brought to notice about four years ago in a lecture by President Morton before the Society of Gas Lighting.† The electric light efficiencies given in the two lines added to the table compiled by Mr. Preece are calculated from the electrical energy. To compare with the other figures which show the proportion of the heat of combustion which is transformed into light energy, we must employ the heat of combustion of the coal instead of the electrical energy, as a starting-point from which to calculate the efficiency. In other words, we must apply the correction for engine efficiency mentioned by Professor Thurston at the close of the table. For example, if the engine driving the dynamos requires $2\frac{1}{2}$ lbs. of coal per. hour per indicated horse-

* Author's Closure, under the Rules.

† *American Gas Light Journal*, February 4, 1889.

power, its efficiency will be about 7½%. If, therefore, the commercial efficiency of generating the electricity is 80%, the combined efficiency is 6%. The watts per candle power given in the table should therefore be multiplied by 100 ÷ 6 in order to obtain the equivalent of the heat generated by the coal, and the efficiency calculated from the electrical energy should be divided by this quantity in order to obtain a figure that will correspond to the values given for oil and gas. In the case of the incandescent light this correction brings the efficiency in line with that of gas or oil lamps. The increase of efficiency of the incandescent light with an increase of temperature of carbon, as shown by the experiments of Professors Nichols and Merritt, has been appreciated by electricians for many years. Before the introduction of the incandescent electric lamp, experiments were made by M. Edmond Becquerel on platinum wire made incandescent by means of an electric current, and it was shown that the efficiency increased very rapidly as the temperature of the wire was made greater.* Since this time experiments have been made by many investigators. In 1868 F. P. Le Roux reviewed the work of M. Becquerel and used his determinations in estimating the probable temperature of an arc lamp.† In 1881 an exhaustive report on the efficiency of the incandescent electric lamp was presented by President Morton to the Light House Board. In this report curves were given to show the increase of efficiency with an increase of temperature or horse-power required to operate the lamps.‡

It is also stated that the arc lamp is a little better than the incandescent lamp, and the figures given in the table indicate that it is only twice as efficient. As the arc lamp is ordinarily employed where the light is required at a distance, the rays which are thrown directly downward, or at a small angle from the vertical, effect but a small portion of the illumination. The efficiency of illumination when this feature is considered is ordinarily over five times that of an incandescent lamp. In a test made some time ago on lights used for street illuminating purposes, the candle

* *Recherches sur la determination des hautes températures au moyen de l'intensité de la lumière émise par les corps incandescents ;* par M. Ed. Becquerel, *Comptes Rendus*, Vol. LV., 1862, p. 826.

† *Les Machines Magnéto-Électriques Françaises et l'Application de l'Électricité ;* par F. P. Le Roux, 1868.

‡ Appendix to the Annual Report of the Light House Board for the year ending June 30, 1880.

power at angles varying from 30° to 45° below the lamp was found to average about 800. These lamps required about ¾ H.P. each at the dynamo shaft, or an electrical horse-power of about one-half, so that the watts per candle power was about .5, which is about one-eighth the amount required by an incandescent lamp, if the candle power be measured over the same angles.

In the tests of carbons for arc lamps made at the International Electrical Exhibition in 1884, the watts per candle power, taken over a range of 15° to 45° below the horizontal, is .70 for the Brush (1,200) lamp and .57 for the Brush (2,000) lamp.* This figure varied from .61 to 1.46 watts per candle power in seven other forms of lamps tested. Employing the figures for the Brush lamp, we have an efficiency from 7 to 9 times that of the incandescent lamp.

No measurements were made of the candle power beyond a position 60° below the horizontal plane in the tests of carbons just quoted. We are therefore unable to apply the method of determining the spherical candle power given in the appendix of my paper, without making some assumption in regard to the intensity of the light thrown downward. Assuming that no light is thrown downward at 75° and 90°, and applying the above method of determining the spherical candle power, we obtain values, neglecting the shadows cast by the side bars of the lamp, which will be slightly too small. The watts per spherical candle power below a horizontal plane, not corrected for the shadows cast by the side bars, will be 0.90 for the (1,200) lamp and 0.67 for the (2,000) lamp, which correspond to efficiencies 5.6 and 7.5 times that given in the table for the incandescent light.

If a shade or reflector be used in connection with the incandescent lamp, the watts per spherical candle power measured below a horizontal plane may be less, in practical running conditions, than the value given by Professor Thurston, and the economy would be correspondingly increased. The economy of the arc lamp in cases where the light is required over a large area would still, however, be much more than twice that of the incandescent.

* Report of examiners of Sections V., VI., and VIII.: Electric lamps ; carbons for arc lamps. International Electrical Exhibition, 1884. These tests include measurements in a horizontal plane and at 60°, which are not considered in the calculations given above.

DXX.*

PERFORMANCE OF AN OVERHEAD TRAVELLING CRANE, OPERATED BY A SINGLE ELECTRIC MOTOR.

BY ANTHONY VICTORIN, WEST TROY, NEW YORK.

(Member of the Society.)

THE accompanying table contains data relative to the performance of an overhead travelling crane at the army gun factory, Watervliet Arsenal, West Troy, N. Y.

The crane (built by the Morgan Engineering Co.) is operated by a single electric motor. The electric current is generated by a Thomson-Houston 65-horse-power dynamo. Its voltage is 500, the speed 1020 R. p. m. The construction of the crane may be seen in Figs. 148, 149, and 150. It has a span of 60 feet, a clear hoist of 40 feet, and a capacity of 120 gross tons. The capacity of the auxiliary hoist is 10 tons, hoist 56 feet. The total weight of the whole crane is about 150 tons. The bridge rests on 8 double-flanged wheels (4 on each side) of 36 inches diameter, the trolley on 16 wheels of 24 inches diameter. All wheels are arranged in pairs in compensating beams to avoid inconvenient results from want of uniformity in the level of the track rails. All wheels have also anti-friction steel roller bearings.

The motor *d* (Fig. 150) is located at one end of the bridge. It receives the electric current through a bare copper wire, *e*, which is strung on insulated rollers along the crane ways. The motor is in permanent gear with the clutch-shaft, *c*. This shaft *c* is fitted with four clutch-gears.

Two square driving shafts, *a* and *b*, are located on the bridge, one on each side. Shaft *a* operates, by means of clutches, the bridge travel and trolley travel and the auxiliary hoist; while shaft *b* operates similarly the main hoist only.

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* Presented at the New York meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

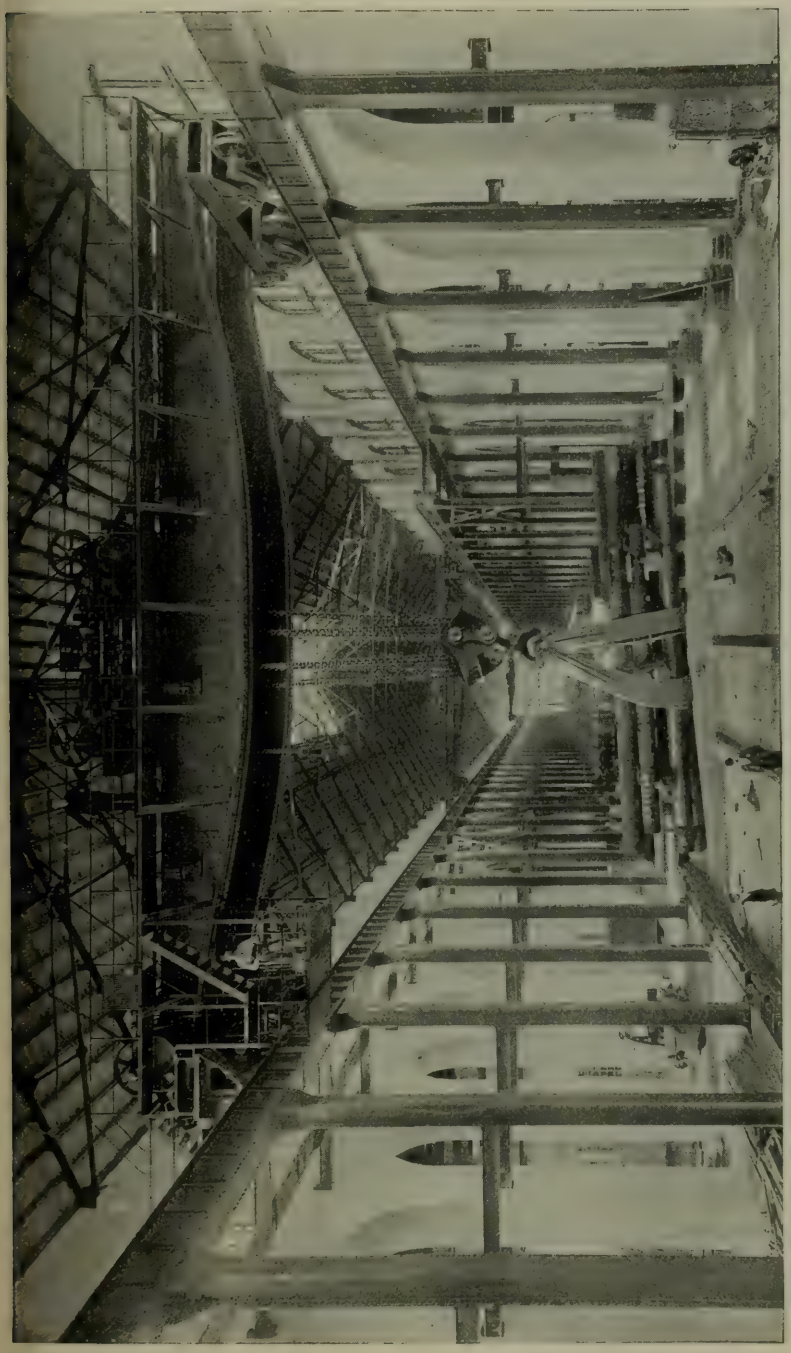


FIG. 148.

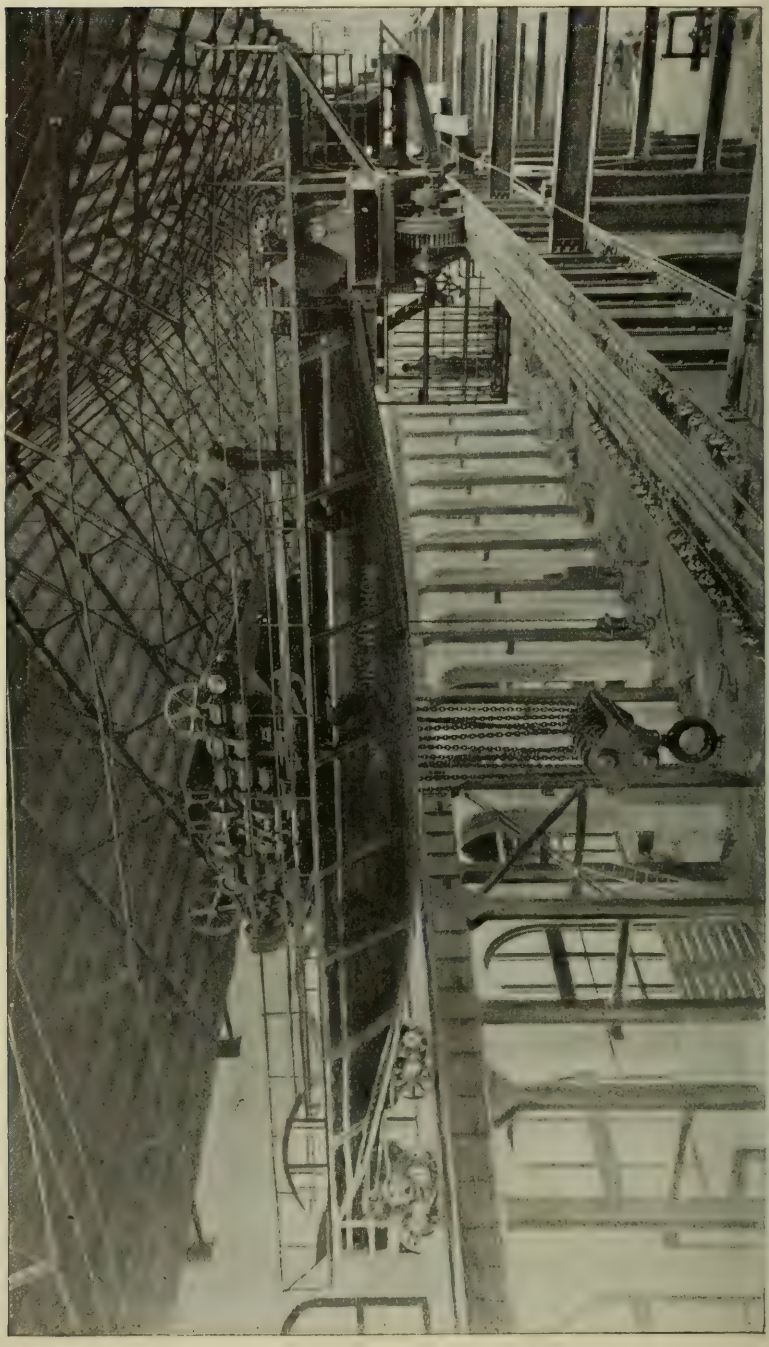


Fig. 149.

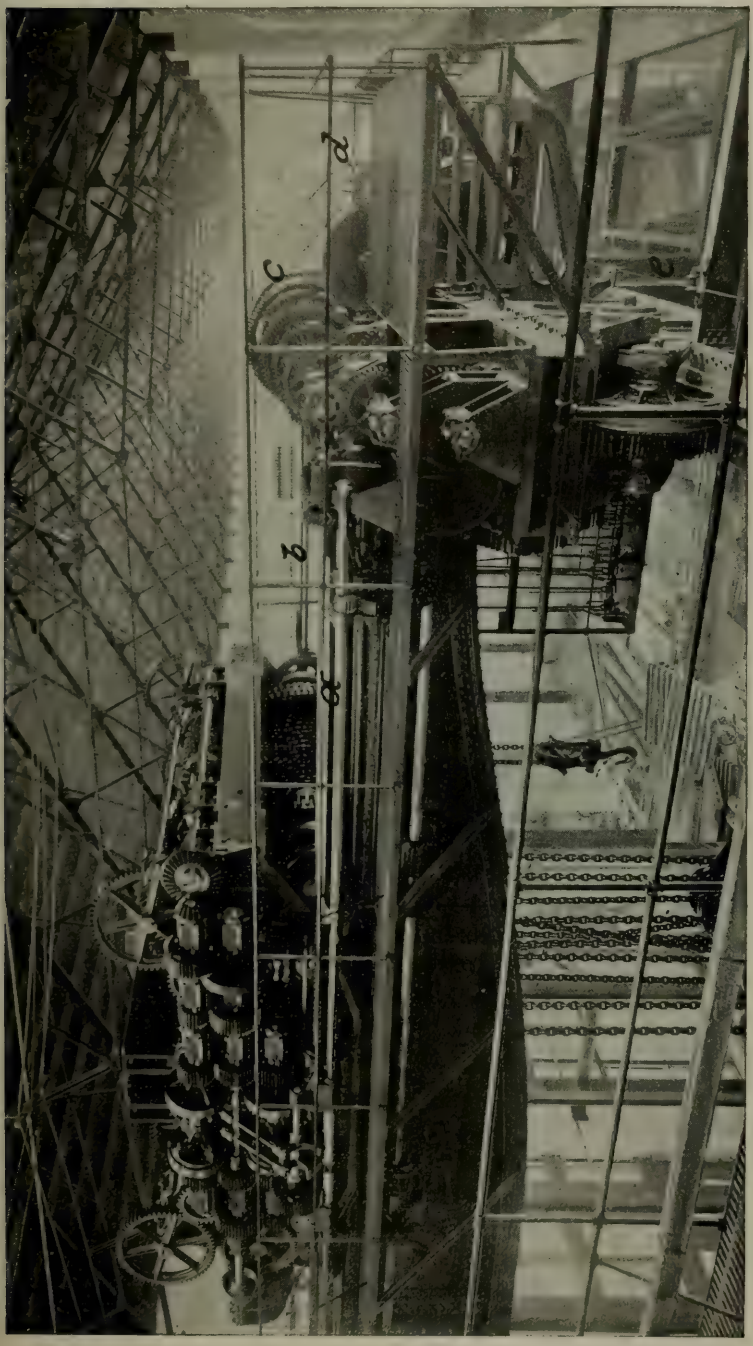


FIG. 150.

The crane performs the following operations:

Bridge travel = 40 and 80 feet per minute.
Trolley " = 50 " 100 " " "
Main hoist = 2, 4, 8, and 16 " " "
Auxiliary hoist = 20 " 40 " " "

Automatic brakes are provided to sustain the load in any position

The trolley is provided with two grooved chain-drums, each being capable of winding 250 feet of 1¼-inch wrought-iron main hoisting chain. These chain-drums revolve loose on trolley axle-shafts 7 inches in diameter, with bronze-bushed bearings of 24 inches length at each end of drums.

The lower chain-sheave block contains 6 bronze-bushed sheaves of 30 inches diameter, while the upper block contains 5 sheaves of 33 inches diameter, each of which swivels independently of the others.

The chain is rove twelve times through the sheaves.

The chain-drum of the auxiliary hoist is located above one of the main chain-drums, and is grooved for a ¾-inch chain of sufficient length for 56 feet hoist.

The operating cage contains all manipulating levers, also the main switch, rheostat, etc.

All motions of the crane can be in operation simultaneously.

All gears of the crane mechanism are carefully cut, except the gears on the chain-drums, which are cast; all bearings have bronze bushings. All working surfaces are finished smoothly and all parts are carefully adjusted.

But notwithstanding all possible care with respect to the construction and the arrangement of the crane mechanism, a great percentage of the driving power is absorbed by friction—as indicated in the last column of the performance table—and the maximum efficiency of the main hoist is about 50%, the lowest efficiency is about 23%.

It may reasonably be assumed that the friction in the mechanism for the bridge travel and the trolley travel attains similar proportions, as given for the hoist; and that the efficiency ranges from about 25% for the slowest speeds, with the greatest number of gear trains in operation, to about 50% for the highest speeds, with fewer parts in operation.

The figures in the table permit various calculations as to the frictional resistance in certain parts of the crane, *i.e.*

Theoretical work of hoisting 120 gross tons 2 ft. p. m.	= 16.29 H.P.	= 24.3 amperes.
Actual " " " " " " "	= 40.2 "	= 60 "
Frictional resistance in crane.....	= 23.91 H.P.	= 35.7 amperes.
Actual work of operating hoist 2 ft. p. m. without load.....	= 10.7 "	= 16 "
Frictional resistance due to the load of 120 tons	= 13.21 H.P.	= 19.7 amperes.

It was observed that the power required to bring the crane mechanism up to speed from the state of rest is considerable, and is from about 30% to 150% in excess of the power required for keeping an operation in continuance.

The table indicates also that no noticeable reduction or change occurred in the friction of the crane mechanism during a four-months' run from June 8, when the crane was first put in operation. The crane was in continual service during that period in handling various loads up to 60 tons. This may be an indication of good workmanship and large wearing surfaces.

Volts and amperes were actually measured in every test at the poles of the motor, and three independent readings were taken in each case. The figures given in the table represent therefore the average result of three tests. The maximum variation in the voltage of any test was less than five volts, hence the voltage was assumed to be practically constant. The only instant when the voltage fell as low as 490 occurred when a load of 30 gross tons was hoisted at a speed of 16 feet per minute. This test was omitted from the table, for the simplification and greater convenience of the latter. Observations were made in many instances at the poles of the generator also, simultaneously with those at the poles of the motor, especially with heavy loads; but the difference in the readings at both ends of the line was inappreciable, and about what was anticipated. The length of the line is about 1,000 feet, and the generator is located in the same building as the crane and at one end of the crane-ways. The instruments used were Weston Direct Reading Standard Ammeters and Voltmeters.

The speed of the armature shaft of the generator was measured during many of the tests and under all conditions of load. The normal speed is 1,020 R. p. m., the slowest speed observed was 1,010 R. p. m., and the highest 1,064 R. p. m. Between these limits the speed was nearly constant under heavy loads. The average speed of 52 observations was 1,028 R p. m.

The table contained in the advance copy of this paper distributed before the meeting was erroneous, because a calibration of the voltmeter, made after this table was printed, showed that it recorded 500 volts when it should have indicated 425 volts only. The interval of time between the calibration of the voltmeter and the date of the meeting enabled me to revise the table and to make a complete and new series of tests in order to verify the correction. The table herewith is thus corrected.

I have made a test recently also of a three-motor electric travelling crane, and present the data obtained, in the appendix, with such additional information as regards the description of the crane as was furnished me.

PERFORMANCE OF AN OVERHEAD TRAVELLING CRANE, OPERATED BY A SINGLE ELECTRIC MOTOR, AT THE ARMY GUN FACTORY, WATERVLIET ARSENAL, WEST TROY, N. Y.

Voltage = 500.

Operation.	Test of June 8, 1892.		Test of October 8, 1892.		Load.	Maximum amperage observed in starting.		Theoretical H.P.	Percentage of efficiency (October test).
	Amperes.	E.H.P.	Amperes.	E.H.P.		June.	October.		
Motor and clutch-gears	4	2.7	4	2.7	No load.	..	..	.....	.. ..
Square shaft for main hoist	7	4.7	6	4.0		..	..	.....	.....
Square shaft for bridge and trolley travel	8	5.4	6	4.0		..	..	.....	.....
Both square shafts	13	8.7	10	6.7		..	..	.....	.....
Bridge travel, 40 ft. p. m.	12	8.0	12	8.0		..	25	.....	.....
" " 80 " "	19	12.7	20	13.4		..	45	.....	.....
Trolley travel, 50 " "	12	8.0	10	6.7		..	15	.....	.....
" " 100 " "	18	12.1	18	12.1		..	33	.....	.....
Main hoist, 2 " " hoist	12	8.0	12	8.0		..	18	.....	.....
lower	8	5.4	4	2.7		..	18	.....	.....
" " 4 " " hoist	18	12.1	18	12.1		..	50	.....	.....
lower	11	7.4	8	5.4		..	48	.....	.....
" " 8 " " hoist	23	15.4	26	17.4		55	60	.....	.....
lower	10	6.7	6	4.0		35	45	..	.....
Auxiliary hoist, 20 " " hoist	10	6.7	10	6.7		18	..	.....	.....
lower	9	6.0	8	5.4		..	..	.....	.....
" " 40 " " hoist	16	10.7	18	12.1		35	..	.....	.....
lower	13	8.7	14	9.4		30	..	.....	.....
Bridge travel, 40 " " Trolley " 50 " "	17	11.4	16	10.7		..	42	.....	.....
Bridge travel, 80 " " Trolley " 100 " "	24	16.1	24	16.1		..	55	.....	.....
Bridge " 40 " " hoist	22	14.7	22	14.7		..	40	.....	.....
Trolley " 50 " " lower	17	11.4	16	10.7		..	..	.....	.....
Main hoist, 2 " "									
Bridge travel, 80 " " hoist	43	28.8	48	32.2		..	80	.....	.....
Trolley " 100 " " lower	24	16.1	24	16.1		..	..	.....	.....
Main hoist, 8 " "									
Bridge travel, 40 " "	16	10.7	14	9.4	30 gross tons.	..	30	.....	.....
" " 80 " "	26	17.4	24	16.1		..	55	.....	.....
Trolley " 50 " "	12	8.0	12	8.0		..	30	.....	.....
" " 100 " "	24	16.1	20	13.4		..	40	.....	.....
Main hoist, 2 " " hoist	24	16.1	26	17.4		..	60	4.07	23.4
lower	3	2.0	2	13.4		..	..	.....	.....
" " 4 " " hoist	42	28.2	42	28.2		..	80	8.14	28.9
lower	0	0	0	0		..	45	.....	.....
" " 8 " " hoist	56	37.5	60	40.2		..	110	16.29	40.5
lower	0	0	0	0		..	45	.....	.....
Bridge travel, 40 " "	18	12.1	16	10.7	60 gross tons.	..	30	.....	.....
" " 80 " "	24	16.1	24	16.1		..	65	.....	.....
Trolley " 50 " "	14	9.4	12	8.0		..	23	.....	.....
" " 100 " "	22	14.7	20	13.4		..	65	.....	.....
Main hoist, 2 " " hoist	30	20.1	30	20.1		..	55	8.14	40.5
lower	0	0	0	0		..	30	.....	.....
" " 4 " " hoist	52	34.9	56	37.5		..	70	16.29	43.4
lower	0	0	0	0		..	60	.....	.....
" " 8 " " hoist	..	....	96	64 3		..	..	32.58	50.7
lower	..	....	0	0		..	..	.....	.....
Bridge travel, 40 " "	16	10.7	18	12.1	120 gross tons.	.	42	....	.....
" " 80 " "	32	24.1	36	24.1		.	70	.....	.....
Trolley " 50 " "	16	10.7	18	12.1		..	35	.....	.....
" " 100 " "	36	21.4	32	21.4		..	65	.....	.....
Main hoist, 2 " " hoist	64	42.9	60	40.2		..	110	16.29	40 3
lower	0	0	0	0		..	45	.....	.....
Auxiliary hoist, 20 " "	30	20.1	28	18.8	10 gross tons.	..	..	13.58	72.2
" " 40 " "	38	25.5	36	24.1	5 gross tons.	..	..	13.58	56.3

APPENDIX.

The following data represent the performance of an overhead travelling crane at the Pond Machine Tool Works, Plainfield, N. J.

The crane is of the "Shaw" type, has a span of 41 feet, and a capacity of 15 tons. It is operated by a generator of 30 H.P., speed 750 R. p. m., built by the United States Electric Lighting Co., of Newark, N. J. The current is transmitted to the crane by means of two No. 00 (B. & S.) hard-drawn copper mains strung along the bridge. The operations of the crane are performed by three series wound motors, built by the U. S. E. L. Co.

The motor for the bridge travel is located at the end of the bridge, and is stated to be of 6 H.P. The motors for trolley travel and hoist are located on the trolley, the former, it was stated, having a capacity of 2 H.P., the latter of 8 H.P.; voltage, 220.

The bridge rests on a truck on each end, having two double-flanged wheels of 24 inches diameter. The trolley rests on four double-flanged wheels of 14 inches diameter. The hoist motor drives a double drum hoist by means of bevel gears and worms. The hoist has a brake to stop the armature shaft after the current is broken. This brake consists of a pair of solenoids in series with the hoist motor that operates the halves of a friction clutch on the circumference of a drum of 7 inches diameter and 3 inches in width. The hoist is provided with a brake to prevent the load from driving the motor.

The speed of the motors is regulated by rheostats, the contact arms of which are operated in unison with the reverse switches by means of three levers in the crane cage. The reversing of the motors is accomplished by a reversing switch, which reverses the direction of the current in the armature.

No special attention was given to the condition of any part of the crane or the crane run-ways, as it was the intention to obtain data showing the results obtainable under ordinary conditions.

The figures given in the table are in each case the average of three independent readings or tests. Volts and amperes were

actually measured at the poles of the motors in each case. The voltage was normal and constant during all tests except the one marked thus *, when it fell to 210. The instruments used were Weston Direct Reading Standard Ammeters and Voltmeters.

PERFORMANCE TABLE OF A 15-TON THREE-MOTOR ELECTRIC OVERHEAD TRAVELLING CRANE.

Voltage = 220.

Operation.		Amperes.	E.H.P.	Load in tons of 2,000 lbs.	Maximum amperage observed in starting.	Theoretical H.P.	Percentage of efficiency.
Bridge travel	150 ft. p. m.	16	4.7		18		
	300 " "	20	5.9		48		
	75 " "	16	4.7	5	35		
	300 " "	22	6.5	5	75		
	60 " "	18	5.6	10			
	300 " "	25	7.4	10	70		
	40 " "	23	6.8	15	30		
	300 " "	28	8.2	15	80		
Trolley travel	40 " "	4	1.2		6		
	100 " "	5	1.5		15		
	30 " "	4	1.2	5	6		
	100 " "	5	1.5	5	18		
	30 " "	4	1.2	10	8		
	100 " "	5	1.5	10	16		
	25 " "	5	1.5	15	8		
	100 " "	6	1.8	15	20		
Hoist	25 " " hoist	15	4.4		80		
	lower	20	5.9				
	2.5 " " hoist	40	11.8	5	46	0.76	6.6
	lower	20	5.9	5			
	15 " " hoist	33	9.7	5	100	4.54	46.4
	lower	20	5.9	5	65		
	3.5 " " hoist	43	12.7	10		2.12	17
	lower	26	7.7	10			
	15 " " hoist	53	15.63	10	82	9.09	58
	lower	26	5.9	10	65		
	3.5 " " hoist	66	19.46	15	84	3.18	16
	lower	26	7.7	15	30		
	10 " " * hoist	64	18.	15	105	9.09	50.5
	lower	18	5.3	15	62		

NOTE.—All speeds given in the above table for travel and hoist represent the maximum and minimum obtained for continuous work.

DISCUSSION.

Mr. J. S. Bancroft.—I have a record of a test made recently in our works on one of our 50-ton cranes driven by a single motor. The current was of 220 volts potential at the motor brushes, and one ampere would be equivalent to .2949 of a

horse-power. To hoist the empty hook at the rate of 5 feet per minute required 20 amperes, or 5.898 H.P.; to hoist a load of 44,000 lbs. at the same rate of 5 feet required 50 amperes, or 14.745 H.P. The net horse-power represented by 44,000 lbs. lifted 5 feet in one minute is 6.666 H.P., leaving 8.079 required to drive the motor and crane under this load. The efficiency of the crane under this load of less than half the capacity of the crane was 45.2%. The frictional resistance due to this load is 8.079 H.P. — 5.898 H.P., equals 2.181 H.P., which is 32.7% of the net horse-power. Assuming this to be true for the full load of the crane, we would have :

To lift 112,000 lbs. 5 feet per minute net horse-power	16.96
Resistance due to load, 32.7% of 16.96	5.556
To lift hook as above	5.898
	28.414

making the probable efficiency of the crane with full load 59.6%, and as this work represents only 80% of the motor capacity, the efficiency would probably be slightly above this.

Mr. Oberlin Smith.—I do not see, if, as the description seems to show, a worm gear is used to do the hard work of hoisting in this Shaw crane at Plainfield, how the efficiency for any load under any conditions can average as high as 50%, because wherever such gear is used there is usually a loss in excess of this amount. There must be a mistake in figures where such high efficiency is given.

Mr. Victorin.—Mr. Smith is correct about the worm gear in this crane.

Mr. H. C. Spaulding.—I would like to ask if the voltage was assumed constant at 220, and whether the reading was taken at the same time with both the voltmeter and the ammeter.

Mr. Victorin.—The voltage was 220 in all the tests reported, and the reading of both instruments was taken at the same time. The voltage in the test of the Pond crane varied more, but in no case was the variation higher than ten volts.

Mr. M. P. Wood.—Was the speed of hoist actually ascertained or only assumed, and did the time of measurement include the start?

Mr. Victorin.—The speeds were measured with a tape line attached to the crane hook to which the load was suspended, and the measurement commenced after the crane was in opera-

tion and did not include the start. The same plan was pursued for the bridge travel, and each measurement was made three times.

Mr. J. F. Holloway.—This is certainly a very interesting subject, and it is one which is going to be still more so, for the reason that the transmission of power through electric motors is now coming into very extensive use, and those who so far have had any experience have been themselves somewhat surprised at the results obtained. It is as yet unknown as to what the practical efficiencies are of the various motors in use, and it would seem a justice to Mr. Victorin, who has certainly given this subject a great deal of care and study, that he be permitted to present for publication in the *Transactions* of the Society the corrected table as presented by him at this meeting. The paper seems to be such a valuable one, that before going on record in the printed *Transactions* it should be perfectly clear and perfectly satisfactory to the writer and to the Society.

*Mr. Victorin.**—In reply to the revised debate, I would like to call attention to the method employed by Mr. Bancroft in calculating the probable efficiency of a 50-ton crane for the maximum load of the crane, from data which were obtained with a test load of about 40% of the maximum load. This method, if employed with reference to the results given in the performance table of the 120-ton crane, is not quite confirmed by the facts, as will be shown in the following:

Power required to hoist the empty hook 2 ft. p. m.	= 8.0 H.P.
" " " " 60 gross tons 2 " "	= 20.1 H.P.
Theoretical power to hoist 60 gross tons 2 " "	= 8.14 H.P.
Power required to drive motor and crane	= 11.97 H.P.
Efficiency	= 40.5%.

The frictional resistance due to the load of 60 gross tons is 11.97 − 8.0 = 3.97 H.P., which is nearly 48.8% of the theoretical horse-power. Assuming this to be true for the full load of the crane, which is 120 gross tons hoisted 2 feet per minute, we would have:

Theoretical power to lift 120 gross tons 2 ft. p.m.	= 16.29 H.P.
Resistance due to load, 48.8% of 16.29	= 7.94 H.P.
To lift hook as above	= 8.00 H.P.
	32.23 H.P.

* Author's Closure, under the Rules.

This would make the probable efficiency with full load 50.5%, while it is, according to the results actually obtained, only 40.3%, notwithstanding that the total work represents only 64% of the nominal motor capacity.

I wish to remark furthermore, that the object of the tests presented by me at this meeting was solely to represent the efficiency of the cranes in combination with their motors as machines or appliances, without investigating the electrical conditions of the remainder of the plant, otherwise than to see that they were in proper order.

As regards the "Shaw" crane, I would like to say this, that the crane is so proportioned that it works at its best efficiency when handling not more than about $\frac{1}{2}$ of its full load, as in nearly all shops a large majority of the loads lifted will not exceed this. As the loads get heavier, the efficiency will decrease, until when handling full loads it will be 50% and even less. The limiting of the sizes of the motors Mr. Shaw believes to be a very useful safety device, inasmuch as, with the proportions which he uses, there is not sufficient lifting power to *strain seriously any part of the mechanism*, or to pull the crane down. The habit of many shops is to lift whatever the crane has occasion to handle, without regard as to whether it is in the capacity of the crane or not, provided there is sufficient power to do the work. In one instance, a 20-ton crane has repeatedly handled from 30 to 33 tons, and has not handled heavier loads simply and only because, with the motors used on the crane, the users have not been able to lift the overload clear of the floor.

DXXI.*

TESTS ON THE TRIPLE ENGINE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

BY C. H. PEABODY AND E. F. MILLER.

(Members of the Society.)

THE tests described in this paper, and for which the data and results are given in the accompanying tables, were a part of the regular work in the laboratory of steam engineering at the Massachusetts Institute of Technology, for the school year of 1891–92. They are reported here because they are believed to be of value to the engineering profession; and in order that they may receive the attention which we believe they deserve, it is proper that we should state our reasons for our confidence in their accuracy and correctness, especially as student work is sometimes considered of little value. The observers, who were students of the third-year class, and who had already received instruction from preliminary tests of like nature but which are not reported here, were in divisions of about twenty, each under the direction of the instructor in charge of the laboratory, aided by three competent assistants. All the instrumental work, such as weighing water, reading gauges, and taking indicator diagrams, received close and unremittent attention from the instructors. The measurements of areas and pressures on the indicator diagrams were made independently by two observers, and checked. All the calculations for all the tests were carried through by the instructing force and thoroughly checked. Finally, it is believed that an inspection of the results of the tests, as given in the table and the accompanying diagrams, will show that the variations of results of comparable tests are well within the limit of the errors of observation. Thus the tests No. 1 and No. 2 may be considered to be duplicates; their consumptions of heat are 233 and 237 B. T. U. per horse-power per minute; the difference, 4 B. T. U., is less than two per cent.

* Presented at the New York Meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

Other pairs, such as No. 3 and No. 4, No. 5 and No. 6, show a like satisfactory result, while none of the results reveal notable discrepancies.

The engine, which has already been presented to the attention of this Society, has provision for jacketing the barrels and heads of the cylinders and the intermediate receivers. The tests given here are the beginning of a series which are intended to show what advantage, if any, may be obtained by jacketing the various organs of the engine with steam. While the engine is provided with the necessary piping, valves, etc., for running in various combinations, and while the cranks may be set at various angles, it was run in the usual way for a triple engine with the steam passing in succession through the high pressure cylinder, the first receiver, the intermediate cylinder, the second receiver, and the low pressure cylinder, and then to a surface condenser; and the cranks followed at 120° in the order of high, intermediate, and low pressure. The priming in the steam near the throttle valve was 1.1 per cent. for all the tests. The steam in the jackets was at boiler pressure and was assumed to have the same quality. The steam condensed in the condenser was collected and weighed in tanks; the drain from the several jackets was caught and measured in graduated receivers. All the tests were one hour in duration.

Some of the principal dimensions of the engine are given in the following table:

HIGH.

Diameter	8.99 in.
Stroke	30.00 in.
Diameter piston rod	2.19 in.
Clearance in per cent. of piston displacement	C.E. 9.76 H.E. 8.83
Piston displacement	C.E. 1.037 cu. ft. H.E. 1.102 cu. ft.

INTERMEDIATE.

Diameter	16.01 in.
Diameter rod	2.19 in.
Stroke	30 in.
Clearance in per cent. of piston displacement	C.E. 10.9 H.E. 10.4
Piston displacement	C.E. 3.430 cu. ft. H.E. 3.495 cu. ft.

LOW.

Diameter	24.063 in.
Diameter rod	2.16 in.
Stroke	30 in.
Clearance in per cent. of piston displacement	C.E. 12 27 H.E. 12.18
Piston displacement	C.E 7.831 cu. ft. H.E. 7.894 cu. ft

The surface condenser into which the engine exhausts is used for a variety of laboratory work, and has various pipes entering it, each with its valve. The spindles of these several valves, though tight under steam pressure, could not be prevented from allowing air to leak into the condenser at varying rates. Thus, the vacuum was never satisfactory and varied from day to day; it was, however, possible to maintain it steady during a single engine test. Since the performance of a multiple expansion engine depends largely on the vacuum, it has been considered advisable to reduce all the tests to the same vacuum. The table gives the steam per horse-power per hour, and the B. T. U. per horse-power per minute actually consumed. Also the B. T. U. per horse-power per minute calculated on the following assumptions: (1) that the vacuum was always 26 inches of mercury, and (2) that the mean effective pressure for the low-pressure cylinder was increased (or diminished) by the difference between the actual and the assumed absolute pressure in the condenser.

The tests may be arranged in five groups, as follows:

1. The first nine tests recorded in the table were made with steam supplied to the jackets on the three cylinders of the engine, but not to the receiver jackets. This series is the most complete and gave the best economy. The results of the tests are plotted on Fig. 151 with the per cent. of cut-off on the high-pressure cylinder for abscissæ and with the B. T. U. per horse-power per minute for ordinates, the latter beginning at 230 on the diagram in order that a large vertical scale may be used without undue size for the plate. The curve drawn to represent these tests shows that the best performance of the engine is obtained with the cut-off on the high-pressure cylinder at 30 per cent. of the stroke, and that longer cut-off and more power requires more heat per horse-power. The cut-off on the intermediate and low-pressure cylinders for this series, and indeed for all the tests reported, was set to give an expansion in the high-pressure and intermediate cylinders, down to or nearly to the back pressure lines for those cylinders, and thus to avoid loops or appreciable drop to the receiver. It will be noticed that the vertical displacement of the points representing tests No. 1 to No. 7, from the curve, is not more than $2\frac{1}{2}$ thermal units; the displacement of the tests No. 8 and No. 9 is about 5 thermal units, but they, with No. 7, sufficiently determine the general direction of the curve, which has the well-known form of such curves showing a gradual reduc-

tion of heat consumption as the cut-off is shortened till a minimum is reached, and beyond that, a large and rapid increase in the heat consumption.

The action of the steam-jackets and the interchange of heat between the steam and the cylinder walls is roughly indicated by the per cent. of steam at cut-off and release. In the high-pressure cylinder we find the familiar initial condensation and re-evaporation, the action being more marked as the cut-off is shortened. The efficiency of the steam-jacket is shown by the

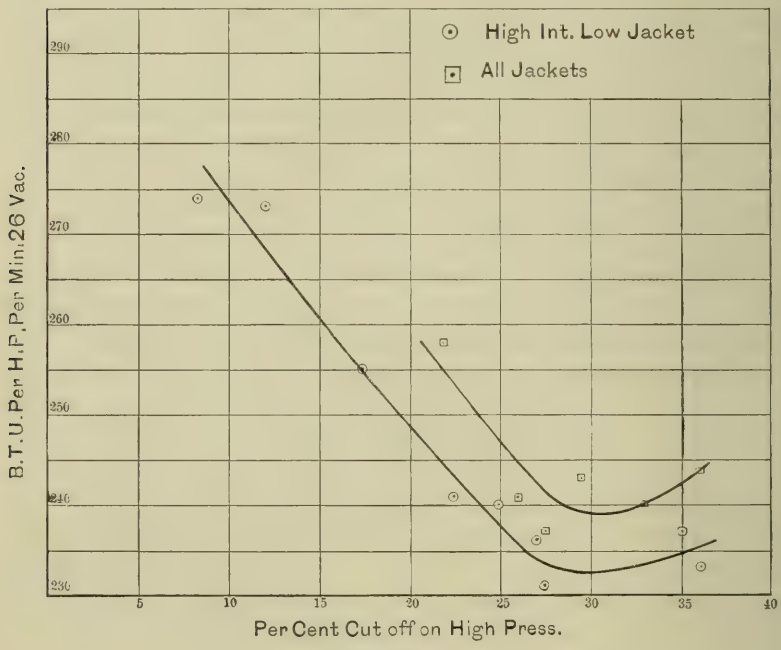


FIG. 151.

fact that the steam is fairly dry at release for all the tests, and with the cut-off at 35% the steam is not very wet even at cut-off. The action in the intermediate cylinder, though less marked and less regular, is similar to that in the high-pressure cylinder. For all the tests except No. 8 and No. 9 the steam is wetter at release than at cut-off, in the low-pressure cylinder, showing a condensation during expansion, a most unexpected result, the more especially as that cylinder was thoroughly jacketed with boiler steam, and there can be no question that there was an energetic action

of the jacket as evinced by the large condensation in that jacket by column 10 of the table.

2. The tests Nos. 10 to 15 inclusive, were made with steam in the jackets of all the cylinders and in the jackets of the intermediate receivers. The results are also plotted on Fig. 151, and are represented by a curve which shows definitely that the minimum consumption for that series is attained at about 32% cut-off on the high-pressure cylinder. The vertical displacement of none of the points representing these tests from the curve exceeds 4 thermal units. A comparison of the columns 20, 21, 30, 31 and 40, 41 of the table, shows that with all the jackets supplied with steam, including those on the receivers, the steam passing through the cylinders becomes progressively dryer in its course through the engine, and is substantially dry and saturated at release from the low-pressure cylinder. It should be remarked that calculations of the quality of the steam in the low-pressure cylinder showed superheating as indicated in the table, at cut-off for all of this group of tests, and at release for two of them. The superheating, however, was in no case large, and in most cases may be within the limits of error of the test. The same action will be observed for the low-pressure cylinder in these tests that was noticed in the first group, namely, that the steam is dryer at cut-off than at release.

The most important conclusion arrived at from a comparison of this group of tests with the first group, is that the application of heat in the jackets was carried to an excess. The excess in the heat consumption at the minimum for this group of tests over that for the first group is only 6 thermal units, but the difference, though small, is distinct. Probably a reduction of pressure of the steam in the jackets of the second receiver and low-pressure cylinder will be found to give a favorable result.

3. The group of tests numbered from 16 to 24 in the table was intended to show the action in the individual jackets. A comparison of tests No. 1 and No. 16 shows that the heat consumption was in the proportion of

$$233 : 269 :: 1 : 1.11,$$

or that the saving from the use of steam-jackets was about 10%, which is what was found to be the gain from jacketing both simple and compound engines in the well-known Revenue Steamer tests by the engineers of the U. S. Navy.

While the tests in the first and second groups show a progressive drying of the steam on its way through the engine due to the action of the jackets, these tests show that the steam, which in the high-pressure cylinder is nearly as dry as in the first groups, becomes progressively wetter, a fact that has been reported for triple expansion marine engines.

A comparison of tests No. 18, No. 19 and No. 20, with tests No. 21 and No. 22, shows that it does not make much difference in

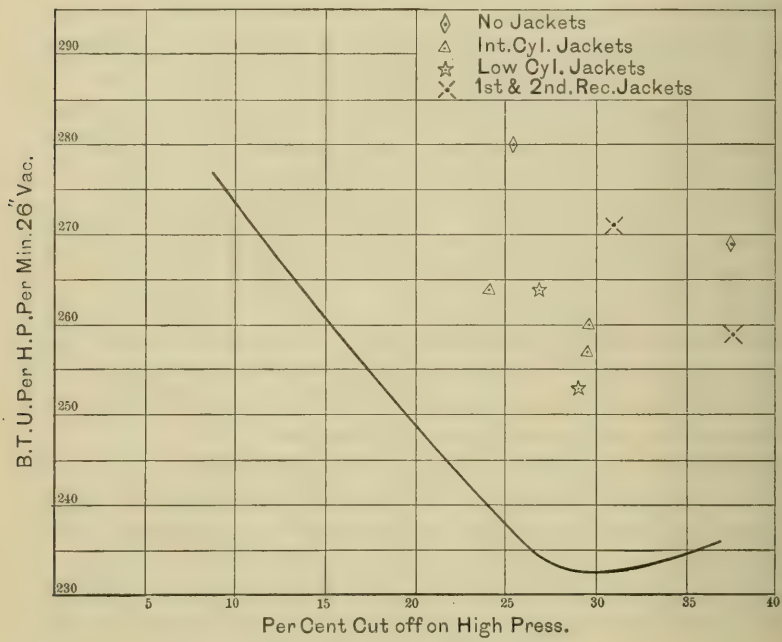


FIG. 152.

economy whether the steam-jacket, if only one is used, be placed on the intermediate or the low-pressure cylinder. A comparison of all five tests mentioned with the tests No. 16 and No. 17 shows a distinct advantage from the use of a jacket on either of these cylinders. This last is more apparent from Fig. 152, on which are plotted the results of all the tests of this third group, together with the curve showing results of the first group of tests, which is given as a sort of standard of comparison.

It is clear from investigation of the table and from Fig. 152, that the use of jackets on the intermediate receivers for tests

No. 23 and No. 24 does not give much advantage ; certainly not so much as the use of a jacket on either the intermediate or low-pressure cylinder. This conclusion of course holds only for this particular type of reheater, and on our engine ; the advantage, if any, to be obtained from the use of other types of reheaters, such as coil or tubular reheaters, and on other types of engines, can be found only by proper tests on such engines.

4. The main interest of the fourth group of tests, which are

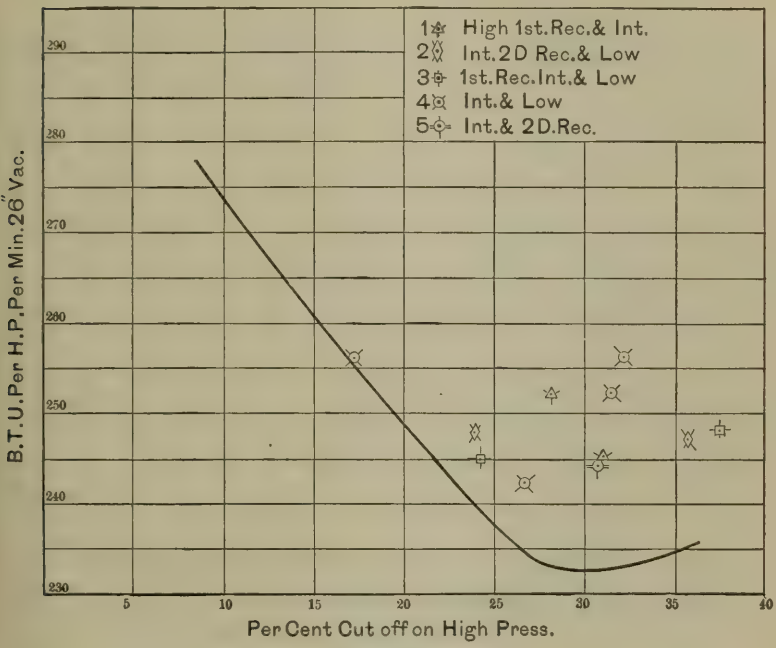


FIG. 153.

plotted on Fig. 153, together with the curve representing the first group, is to see which end of the organs of the engine should be supplied with steam jackets, *i.e.*, whether jacket should be applied to the cylinders and receiver when the steam contained is at high-pressure, or to the cylinders and receiver when the steam is at low-pressure. While the tests are neither sufficiently numerous nor so related as to settle the question, they appear to indicate that it makes little difference which system is used. The comparison of tests No. 29 and No. 30 with No. 27 and No. 28 shows that it makes little difference, if any, which receiver is supplied with a

acket in combination with jackets on the intermediate and low-pressure cylinder. Again, the tests No. 31 to No. 34 with jackets on the low and intermediate cylinders show, on the whole, very similar results at 30% cut-off for the high-pressure cylinder.

5. The last group is made up of a miscellaneous lot of tests that were made somewhat at random to find the effect of various combinations in addition to those already discussed. They are plotted on Fig. 154, together with the curve representing the first

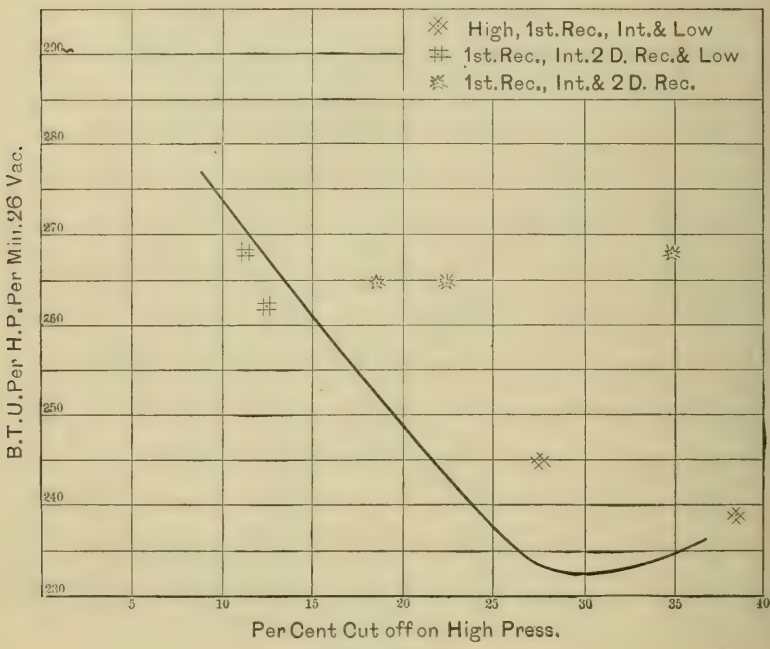


FIG. 154.

group of tests. Together with the tests in the fourth group they show that the jacketing of the three cylinders of the engine (without jackets on the receivers) gives the best result, unless it may be at very early cut-off on the high-pressure cylinder, for which arrangement the economy of the engine is decidedly worse than for a cut-off at about one-third stroke.

The tests No. 38 and No. 39 with jackets on the two receivers and the intermediate and low-pressure cylinders, are the only ones that are represented on the diagram by points that are below the curve of the first group. The importance of tests at so early a

cut-off on the high-pressure cylinder has already been shown to be small.

Though it is too early to announce any definite general conclusion from this series of tests, we have gathered a general idea that it makes but little difference where steam-jackets are used on an engine, provided the jacketing is carried far enough and not too far.

TESTS ON THE TRIPLE ENGINE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

	Date. Month and Day. 1892.	Horse Power.	Steam per Horse Power per Hour.	Steam through Cylinders per hour.	Water by Jackets per Hour.					Revolutions per Minute.	Boiler Pressure (Gauge).	Vacuum in Condenser (inches Mercury).	Barometer.
					High Pressure Cylinder.	First Receiver.	Intermediate Pressure Cylinder.	Second Receiver.	Low Pressure Cylinder.				
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	3/4	140.79	13.82	1647.8	53.3	.....	140.9	.....	104.1	89.93	146.2	24.1	29.8
2	3/15	137.99	13.88	1640.5	40.9	.....	144.9	.....	88.8	90.60	147.0	24.7	30.3
3	3/7	125.37	13.74	1420.5	41.0	.....	138.5	.....	117.2	91.93	146.9	24.5	29.9
4	3/14	123.89	13.74	1405.5	44.7	.....	137.3	.....	114.9	91.55	146.7	25.4	30.1
5	3/22	114.67	14.36	1329.5	45.3	.....	138.3	.....	133.7	92.37	146.6	24.5	30.7
6	4/22	105.32	14.48	1251.0	40.4	.....	132.4	.....	101.0	84.87	145.2	24.3	30.1
7	4/5	103.50	14.71	1210.0	41.9	.....	130.2	.....	139.6	93.15	146.0	26.0	30.2
8	5/13	78.32	15.13	891.5	53.9	.....	132.0	.....	107.5	86.70	147.0	27.4	30.5
9	5/12	67.45	16.00	800.0	52.3	.....	122.4	.....	104.2	87.55	146.7	26.0	30.1
10	4/22	154.16	14.46	1782.5	47.6	84.5	113.5	96.0	105.1	91.20	143.7	24.7	30.2
11	4/22	145.15	14.15	1633.5	46.7	82.7	116.3	69.5	105.2	91.40	143.6	25.0	30.2
12	4/21	137.06	14.34	1545.0	46.4	86.6	118.0	74.9	94.4	91.82	143.2	25.2	30.5
13	3/29	128.82	14.13	1449.0	20.6	67.9	129.0	47.7	106.2	91.83	147.1	24.7	30.3
14	4/19	125.86	14.14	1409.5	45.2	62.6	115.1	66.9	80.9	92.17	145.5	25.5	30.4
15	4/21	120.25	14.58	1358.0	46.1	92.2	96.9	55.7	104.5	92.57	143.7	26.4	30.6
16	2/29	109.74	15.34	1683.0	.....	.....	.....	.....	.....	87.77	145.1	24.8	30.4
17	2/26	89.27	15.81	1411.0	.....	.....	.....	.....	.....	88.95	146.8	25.3	30.3
18	2/25	115.21	15.10	1601.5	.....	.....	138.0	.....	.....	88.87	146.2	24.7	30.3
19	4/21	116.50	14.92	1576.0	.....	.....	162.3	.....	.....	90.15	144.9	24.9	30.5
20	2/23	104.50	15.54	1105.0	.....	.....	113.0	.....	.....	88.87	146.6	24.5	30.7
21	2/19	115.10	15.31	1500.6	.....	.....	.....	.....	182.3	88.40	145.4	25.2	30.4
22	2/18	108.29	15.72	1510.5	.....	.....	.....	.....	192.0	88.16	144.9	24.3	30.2
23	3/24	127.70	15.87	1801.0	.....	81.7	.....	143.2	.....	90.88	145.3	22.6	30.3
24	4/11	119.93	16.08	1692.0	.....	89.4	.....	147.6	.....	91.23	146.2	24.1	30.1
25	4/25	121.88	14.38	1508.0	44.1	86.7	113.5	.....	.....	83.52	145.4	24.7	30.6
26	4/26	113.08	14.36	1384.5	44.4	78.3	116.5	.....	.....	84.05	146.6	26.0	30.5
27	4/15	131.54	14.69	1656.0	.....	.....	90.8	88.3	91.6	89.83	144.4	24.0	30 0
28	4/12	114.17	14.48	1337.5	.....	.....	171.0	54.1	91.1	91.40	146.2	25.5	30.3
29	3/10	151.05	14.74	1851.0	.....	87.9	142.7	.....	144.4	90.63	146.2	24.0	29.9
30	3/8	124.48	14.41	1456.5	.....	99.0	118.8	.....	119.9	91.80	145.5	25.1	29.8
31	4/28	122.33	14.87	1510.0	.....	.....	149.7	.....	159.1	83.32	145.6	25.4	30.3
32	3/3	127.97	14.58	1564.5	.....	.....	168.0	.....	133.0	87.90	145 2	25.4	30.0
33	3/1	120.32	14.34	1451.0	.....	.....	159.0	.....	115.0	88.68	145.2	24.6	30.3
34	4/29	99.23	14.78	1195.0	.....	.....	147.4	.....	124.6	83.32	146.4	25.9	30.2
35	3/21	120.99	16.25	1438.3	.....	.....	173.5	136.0	.....	88.88	145.2	23.1	30.5
36	3/11	151.10	14.37	1779.5	38.1	72.0	138.9	.....	142.6	90.48	145.8	23.5	29.6
37	3/17	130.30	14.29	1530.8	44.1	68.7	102.7	.....	115.7	91.42	146.6	25.0	30.4
38	5/10	88.57	15.15	1032.5	.....	79.4	100.9	43.0	86.2	86.10	146.8	26.2	30.4
39	5/9	83.69	15.53	997.0	.....	72.0	86.4	44.0	100.6	86.53	145.9	26.1	30.4
40	3/31	128.47	16.08	1734.0	.....	113.9	142.0	75.8	.....	90.65	147.2	24.0	30.7
41	4/1	102.98	16.25	1358.8	.....	97.3	162.2	55.0	.....	92.55	146.2	24.0	30.7
42	4/4	101.67	15.49	1316.0	.....	80.7	128.6	50.0	.....	93.05	146.1	25.4	30.3

TESTS ON THE TRIPLE ENGINE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.—*Continued.*

HIGH PRESSURE CYLINDER.

	Initial Pressure.	Per cent. of Cut-off.	Pressure at Cut-off.	Pressure at Release.	Pressure at Compression.	Per cent. of Steam in the Cylinder at Cut-off.	Per cent. of Steam in the Cylinder at Release.	M. E. P. Crank.	M. E. P. Head.	Horse Power.
	15	16	17	18	19	20	21	22	23	24
1	140.5	36.1	136.6	48.1	60.6	.906	.938	46.10	47.76	39.41
2	141.3	35.0	133.1	49.1	58.3	.874	.989	46.11	46.44	39.13
3	140.6	27.3	131.6	37.2	45.3	.841	.935	42.53	47.04	38.49
4	142.3	27.0	131.5	36.3	42.4	.839	.943	46.98	47.96	40.58
5	142.3	25.0	127.3	31.5	33.9	.883	.918	50.00	50.40	43.17
6	140.5	21.9	129.0	28.6	26.0	.759	.869	51.37	52.01	40.95
7	142.0	17.4	128.7	21.9	27.6	.728	.830	41.06	45.17	37.55
8	142.9	12.0	128.6	16.1	19.9	.720	.885	37.16	35.58	29.42
9	140.8	8.3	135.8	12.6	17.1	.697	.880	33.12	30.82	26 08
10	142.1	36.1	133.1	46.4	53.0	.834	.881	51.47	51.09	43.65
11	142.0	32.8	130.8	42.1	48.3	.832	.897	49.86	50.27	42.75
12	141.2	29.3	128.9	36.9	39.5	.809	.883	51.11	52.97	44.63
13	143.0	27.5	129.6	36.5	45.5	.816	.905	45.73	46.69	39.62
14	140.7	25 9	124.1	33.9	39.4	.778	.907	42.36	45.88	38.00
15	141.5	21.9	129.0	27.5	29.3	.757	.847	47.36	50.03	42.12
16	140.9	37.5	135.6	50.8	51.5	.905	.956	49.56	54.31	42.60
17	142.9	25.4	138.7	34.7	35.2	.808	.895	46.27	50.45	40.20
18	142.4	29.6	127.0	40.2	44.6	.717	.818	44.28	46.14	37.52
19	140.4	29.5	128.0	38.2	43.4	.767	.867	46.17	46.50	38.99
20	141.2	24.1	134.6	33.6	36.6	.687	.776	45.22	46.70	38.14
21	141.5	29.1	128.3	37.7	37.2	.802	.889	52.29	52.11	43.06
22	140.3	26.8	131.3	37.1	41.6	.742	.878	44.60	48.18	38.21
23	140.5	37.7	127.0	49.3	55.3	.825	.898	47.56	48.20	40.62
24	141.4	30.9	135.2	40.1	45.9	.802	.850	52.74	52.30	44.72
25	141.5	30.8	133.0	40.4	41.5	.811	.882	53.78	54.22	42.10
26	141.0	28.2	129.7	35.4	40.9	.802	.873	48.90	50.08	38.83
27	137.7	35.7	121.9	42.0	56.9	.810	.860	44.02	43.92	36.86
28	142.7	23.9	128.0	31.0	36.5	.793	.902	45.46	46.32	39.11
29	141.2	37.5	129.6	48.9	58.0	.813	.868	47.54	47.23	40.08
30	140.0	24.3	123.5	31.8	35.5	.731	.833	46.42	46.93	40.00
31	140.9	32.2	135.4	44.4	52.3	.943	.912	46.25	45.91	36.64
32	141.1	31.4	130.5	41.6	48.7	.816	.886	43.04	45.61	36.40
33	140.6	26.6	123.1	34.1	32.9	.781	.865	46.88	52.40	41.16
34	144.0	17.3	128.5	21.1	24.6	.677	.766	47.16	45.23	36.75
35	141.4	30.7	129.6	40.4	50.0	.776	.850	47.80	48.20	39.83
36	144.9	38.5	132.8	52.8	65.8	.858	.938	45.51	43.43	37.53
37	139.8	27.6	132.5	36.7	42.7	.793	.850	48.10	46.64	40.40
38	141.9	12.5	131.9	17.8	21.7	.656	.812	37.48	36.46	29.70
39	139.4	11.3	134.9	17.1	21.2	.653	.824	35.80	33.46	27.93
40	143.0	34.8	131.6	48.7	69.2	.802	.896	38.22	38.85	32.61
41	141.7	22.4	128.3	29.6	37.1	.755	.861	43.34	45.80	38.52
42	140.1	18.6	131.3	26.4	34.9	.703	.845	40.42	40.65	35.21

TESTS ON THE TRIPLE ENGINE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.—*Continued.*

INTERMEDIATE CYLINDER.

	Initial Pressure.	Per cent. Cut-off.	Pressure at Cut-off.	Pressure at Release.	Pressure at Compression.	Per cent. of Steam in the Cylinder at Cut-off.	Per cent. of Steam in the Cylinder at Release.	M. E. P. Crank.	M. E. P. Head.	Horse Power.
	25	26	27	28	29	30	31	32	33	34
1	48.9	19.5	44.9	1.9	3.0	.829	.910	17.25	18.34	48.37
2	48.8	19.0	42.3	2.1	3.5	.798	.933	17.12	17.04	46.76
3	40.1	19.0	34.9	−0.6	1.7	.804	.927	13.91	14 95	40.10
4	35.1	22.0	28.8	−0.3	1.6	.797	.946	13.14	13.45	36.79
5	26.3	25.0	22.0	−1.7	0.4	.796	.931	11.15	10.72	30.52
6	22.1	28.0	17.4	−1.9	−0.9	.752	.892	10.98	10.69	27.79
7	20.4	29.0	15.8	−2.0	0.4	.821	.976	8.56	8.47	23.97
8	15.9	21.0	12.6	−5.9	−4.8	.719	.912	8.39	7.87	21.30
9	13.6	20.0	10.8	−6.3	−5.0	.758	.946	7.18	6.92	18.88
10	44.6	26.0	37.7	1.9	4.2	.847	.870	18.82	18.80	51.69
11	55.4	26.0	33.7	1.8	3.9	.852	.937	16.56	16.20	45.34
12	32.8	29.0	27.6	0.3	2.2	.866	.913	15.28	14.79	41.60
13	35.4	26.0	28.7	1.2	4.8	.852	.994	12.64	12.27	34.56
14	34.2	25.0	27.3	0.3	2.2	.841	.979	13.47	13.31	37.30
15	25.5	34.0	19.9	0.9	4.0	.901	Sup.	9.64	9.61	26.84
16	45.6	16.5	38.2	1.7	3.8	.640	.878	12.43	12.38	32.90
17	30.7	17.0	24.4	−1.8	0.4	.594	.853	9.51	8.75	24.53
18	40.4	21.3	33.8	−1.2	−0.2	.699	.735	16.38	16.52	44.18
19	38.1	19.0	32.3	−1.3	−2.1	.716	.818	17.23	16.54	45.99
20	32.2	22.0	27.3	−2.1	−1.0	.668	.746	13.16	14.11	36.63
21	32.3	19.3	25.9	−1.0	−0.2	.626	.849	10.96	11.45	29.94
22	36.4	15.5	29.6	−0.3	1.5	.579	.842	9.94	10.55	27.29
23	47.6	18.0	39.4	1.7	2.2	.667	.849	17.59	15.68	45.66
24	35.6	20.0	29.1	−0.9	−0.1	.645	.777	14.91	13.57	39.24
25	36.1	28.0	28.7	−0.6	−2.2	.841	.832	19.74	19.03	48.92
26	34.3	23.0	30.3	−1.7	−3.5	.832	.851	18.56	17.93	46.33
27	44.7	19.0	37.8	1.6	3.2	.726	.890	16.15	15.04	42.32
28	28.1	24.0	21.5	−2.2	−0.7	.759	.882	11.99	11.52	32.47
29	49.5	23.0	41.4	4.1	6.0	.789	.910	17.99	17.95	49.22
30	30.1	31.5	21.7	0.0	2.1	.834	.926	12.42	12.87	35.09
31	44.6	19.0	37.8	1.5	2.9	.740	.909	16.61	14.86	39.60
32	44.1	19.8	38.7	2.0	4.2	.768	.935	14.71	15.29	39.86
33	28.6	28.5	22.7	−0.1	1.1	.784	.912	12.28	13.46	34.50
34	20.7	28.0	15.6	−2.9	−1.9	.749	.873	10.54	10.46	27.04
35	41.0	21.0	34.6	0.2	0.3	.758	.853	17.17	16.46	45.15
36	55.3	20.0	48.6	4.7	5.8	.830	.962	19.54	19.77	53.75
37	36.5	26.0	30.4	1.0	1.8	.858	.948	15.39	15.38	42.50
38	17.4	32.0	13.6	−2.5	−0.5	.880	Sup.	8.11	7.85	20.76
39	18.2	29.0	14.9	−3.4	−0.3	.880	.982	7.54	7.74	19.98
40	52.8	18.0	45.0	1.3	0.0	.786	.883	20.79	19.44	55.08
41	27.5	28.0	20.4	−1.7	−0.3	.818	.920	12.51	11.79	33.97
42	26.8	27.0	21.5	−2.0	−0.9	.849	.924	12.22	11.62	33.51

TESTS ON THE TRIPLE ENGINE AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.—*Concluded.*

	Low Pressure Cylinder.												
	Initial Pressure.	Per cent. Cut-off.	Pressure at Cut-off.	Pressure at Release.	Pressure at Compression.	Per cent. of Steam in the Cylinder at Cut-off.	Per cent. of Steam in the Cylinder at Release.	M. E. P. Crank.	M. E. P. Head.	Horse Power.	B. T. U. per H. P. per Minute (actual).	B. T. U. per H. P. per Minute, reduced to 26" Vacuum.	Represented on Plates (1 to 4) by
	35	36	37	38	39	40	41	42	43	44	45	46	47
1	2.3	42.4	−1.1	−8.5	−11.2	.909	.861	8.52	8.66	53.01	240	233	
2	2.6	43.5	−2.0	−8.5	−11.2	.894	.895	8.30	8.43	52.01	241	237	
3	0.4	42.4	−3.1	−9.5	−11.7	.935	.880	7.28	7.55	46.78	237	231	
4	0.4	44.1	−3.5	−9.3	−11.9	.944	.921	7.37	7.44	46.52	239	236	
5	−0.3	41.5	−3.8	−9.9	−11.8	.947	.914	6.46	6.47	40.98	247	240	
6	−1.7	53.0	−4.6	−9.7	−11.3	.996	.896	6.10	6.46	36.58	250	241	
7	−0.8	38.9	−4.3	−10.3	−12.1	.949	.911	6.52	6.61	41.98	255	255	
8	−5.0	47.0	−7.8	−11.2	−12.7	.996	Sup.	4.63	4.65	27.60	261	273	
9	−5.8	45.0	−7.8	−11.2	−12.1	.967	.991	3.83	3.89	23.19	274	274	
10	2.3	54.5	−1.3	−7.6	−11.5	Sup.	.951	9.05	9.68	58.82	249	244	
11	2.4	47.4	−0.9	−8.2	−11.7	Sup.	.965	8.87	9.26	57.07	244	240	
12	0.2	53.5	−2.7	−8.2	−11.8	Sup.	Sup.	7.95	8.12	50 83	246	243	
13	3.5	40.2	−1.2	−9.2	−11.8	Sup.	.931	8.68	8.66	54.64	242	237	
14	1.1	46.3	−2.9	−9.3	−11.7	Sup.	.938	7.93	8.06	50.56	243	241	
15	2.6	38.0	−1.9	−8.6	−12.3	Sup.	Sup.	7.96	8.14	51.29	256	258	
16	2.5	21.0	−1.7	−10.4	−11.4	.518	.612	5.63	5.74	34.24	275	269	
17	−1.2	17.6	−4.3	−11.1	−12.2	.459	.624	4.01	4.03	24.54	285	280	
18	−1.0	32.2	−3.9	−9.6	−11.1	.613	.741	5.47	5.52	33.51	266	260	
19	−3.7	50.6	−6.2	−9.9	−11.2	.707	.756	4.99	5.20	31.52	263	257	
20	−2.0	32.2	−4.7	−10.3	−11.3	.629	.736	4.72	5.03	29.73	298	264	
21	−0.3	44.9	−3.9	−9.5	−11.7	.760	.740	6.85	7.03	42.10	257	253	
22	1.2	42.0	−3.3	−9.1	−11.1	.741	.764	6.98	7.17	42.79	274	264	
23	0.8	43.0	−3.4	−8.6	−10.4	.720	.797	6.36	6.92	41.42	275	259	
24	−1.7	45.3	−4.6	−9.1	−10.4	.769	.775	5.60	5.89	35.97	281	271	
25	−3.6	53.0	−6.0	−9.5	−11.3	.731	.790	5.26	5.51	30.86	250	245	
26	−4.5	45.0	−6.2	−10.4	−11.7	.684	.726	4.72	4.96	27.92	252	252	
27	1.5	50.3	−2.1	−8.1	−10.8	.964	.908	8.40	8.59	52.37	255	247	
28	−1.7	53.2	−5.0	−9.6	−12.1	Sup.	.928	6.78	6.80	42.59	250	248	
29	5.0	43.0	0.6	−7.4	−11.4	.932	.915	9.95	9.91	61.75	255	248	
30	1.1	42.8	−2.4	−9.0	−11.8	.963	.915	7.79	7.89	49.39	249	245	
31	2.1	45.0	−2.0	−8.6	−11.2	.897	.890	7.57	8.55	46.09	258	256	
32	3.0	37.6	−1.0	−8.9	−12.0	.878	.852	7.56	8.59	51.71	234	252	
33	0.5	46.1	−3.2	−9.1	−11.5	.942	.909	7.30	7.36	44.61	249	242	
34	−2.9	50.2	−5.6	−9.9	−12.1	.835	.913	5.97	6.13	35.41	257	256	
35	−0.7	42.0	−4.5	−9.0	−10.9	.694	.832	5.74	6.07	36.01	248	234	
36	4.4	43.0	0.1	−7.6	−11.5	.927	.904	9.61	9.66	59.82	247	239	
37	1.4	44.3	−2.9	−8.9	−11.3	.914	.909	7.57	7.51	47.30	249	245	
38	−1.0	42.9	−4.5	−10.3	−11.6	Sup.	.984	6.32	6.58	38.11	261	262	
39	−1.4	39.3	−4.7	−10.8	−12.5	Sup.	.921	5.87	6.18	35.78	287	268	
40	0.4	39.8	−3.3	−9.3	−10.9	.720	.773	6.36	6.75	40.78	277	268	
41	−1.3	30.0	−4.7	−10.5	−11.3	.665	.790	4.69	4.91	30.48	278	265	
42	−1.9	31.5	−5.4	−10.5	−11.9	.666	.792	5.06	5.26	32.95	269	265	

DISCUSSION.

Mr. A. F. Hall.—The only way by which we can ever hope to arrive at rational laws for the construction of the steam engine is by the collection and systematic study of such data as the authors of this paper have so ably presented to the Society. Referring to some investigations on the steam engine, by Prof. Cotterill, Prof. Unwin in a recent paper said:

"There are, no doubt, some people who are in the habit of depreciating quantitative investigations of this kind. They are as wise as if they recommended a manufacturer to carry on his business without attending to his account books. Further, the attempt to obtain any clear guidance from experiments on steam engines has proved a hopeless failure without help from the most careful scientific analysis. There is not a fundamental practical question about the thermal action of the steam engine, neither the action of jackets or of expansion or of multiple cylinders, as to which contradictory results have not been arrived at by persons attempting to deduce results from the mass of engine tests without any clear scientific knowledge of the conditions which have affected particular results. In complex questions fundamental principles are essential in disentangling the results. Interpreted by what is already known of thermodynamic actions, there are very few trustworthy engine tests which do not fall into a perfectly intelligible order."

As an instance of the inaccuracy with which the economy of the performance of various engines is rated, that based upon the weight of steam per indicated horse power per hour may be cited. It is customary for many experimenters to deduct the weight of water entrained, or steam condensed in the pipes, and which has passed through the engine, from the weight of water pumped to the boiler, and from this result deduce the steam consumption of the engine. That such a method is entirely wrong, those acquainted with the fundamental principles of thermodynamics can readily understand. All the entrained water or condensed steam which enters the cylinder carries with it heat, which performs work in that cylinder, and the deduction of such water gives the engine the credit of doing work with less heat than it actually utilized. The object of all calorimetric measurements should be to determine the *quality* of the steam supplied to the engine in order to calculate correctly the amount of *heat* utilized by the

engine. Any assumption as to what the engine would have done with the same boiler pressure, and when supplied with perfectly dry steam is all wrong, because the physical conditions of wet and dry steam, are not the same. It is hoped that some day the engineers will all see the fallacy of rating the performance of engines upon the weight of steam consumed per indicated horse power per hour, except for merely rough approximations: for studying the true merits of the economy of the engine, when considering cylinder condensation ratios of expansion and use of jackets, it is of little value. The steam engine is a *heat* engine and should be so treated in all accurate investigations.

Prof. D. S. Jacobus.—In the absence of Professor Denton, I will present a few remarks which he intended to make on this paper.

Why was not the heat of exhaust measured? In this particular case it would be advisable to do so, for the tests are only one hour long, and were made by students. If a balance of heat was made in each test, it would add greatly to the confidence which most people place in tests undertaken by students.

One-hour tests are reliable, if the important tests are duplicated a sufficient number of times, or if it is proved that the rate at which the water runs from the condenser is so uniform that the per cent. of error involved in starting and ending the tests is a small one. If the rate is determined by noting the weight at ten or fifteen minute intervals, and the weights so obtained are uniform, the sum of a set of readings taken over an hour, or over a shorter time, may be relied on. It is not stated whether this was done in the tests in question.

The absence of sample indicator cards prevents the reader from studying the action of the steam between the cylinders. The tables give the steam unaccounted for by indicator cards between the cylinders, but without the cards before us we cannot determine whether the loss of mean effective pressure is due to drop of pressure or collapse of volume.

A general conclusion is drawn in one portion of the paper, that the saving from the use of the steam jackets was about 10%. As only two one-hour tests were made without jackets, and only one of these is employed in drawing the conclusion, it seems unwise to deduce so far-reaching a statement from the data at hand, when other tests of the effect of jackets indicate such contrary results. For example, a triple-expansion

engine of 750 H.P., without jackets on cylinders or receivers, is reported in *London Engineering*, August 26, 1892, as consuming 12.8 lbs. of water per English horse-power, an economy equal to the best shown by Shroeter's tests of Sulzer triple-expansion engines with jackets on all cylinders and receivers.

Mr. Geo. I. Rockwood.—There is one point to which I would like to call attention, which is illustrated by the curve of efficiency shown in Fig. 151 on page 384. The vertical scale of B.T.U. per I.H.P. per minute being drawn, as it is, so high in proportion to the length of the horizontal scale showing per cent. of cut-off on high-pressure cylinder, one who casually observes the diagram immediately says to himself, "Well, there is only one point of cut-off, after all, in the triple-expansion engine which it is economical to employ; on either side of that we shall run into the same difficulty as we have in the single cylinder engine." He is likely to draw that conclusion, I think, from the steepness of the curve as shown, although not from the facts as presented. I will ask the members to note the point in the curve cut by the ordinate between 15% and 20% cut-off, and then to follow the curve down to the point over 35% cut-off.

As I roughly figure them out, the expansions in the two cases are 40 expansions and 20 expansions; but here is a variation in load of 50%, from a very light load to an average load, while the variation in economy is but 9%, and even with 40 expansions the steam per I.H.P. per hour is only 14.7 lbs., which is still a much better result than can be obtained with the ordinary compound engine, even working with its most economical number of expansions.

This, I believe, is the first authentic series of tests we have, to show conclusively the economy of a steam-jacketed triple-expansion engine with a variable load; a fact which seems contrary to the general impression existing among engineers.

I would like also to draw attention to the mechanical construction of steam-jackets, and to the question of the advisability of jacketing the barrels of low-pressure cylinders. It may or may not be considered an advantage from a theoretical standpoint to jacket the barrel, but however this may be, the actual jacket, as it must be constructed if employed, is one of the mechanical abominations, and it is also one of the things which it is hardest to induce the buyer to buy. But to jacket the heads of the low-pressure cylinder is a very much simpler

matter, the importance of which possibly we do not fully realize. The heads of the low-pressure cylinder are the longest in contact with the steam in proportion to the jacketing surface exposed, for the barrel-jacket is in contact with the working steam only one-half the time, and at no time is it in contact with the entering steam, so that it gets no chance of staying the initial condensation. Jacketing the heads does have that effect, besides lending itself to cheap construction. In the case of the compound engine to which I referred this morning, the head-jacketing of its low-pressure cylinder is accomplished by simply putting a partition in the end of each head; the engine, although very efficiently jacketed as to its receivers, is thus not over-jacketed because the steam per horse-power per hour as measured at release, from the diagram, shows 4% to 5% of moisture. No superheating takes place in the low-pressure cylinder.

The intermediate receiver of this engine is jacketed with 16 brass tubes, each about 8 feet in length, which run from end to end of the receiver. These are filled with steam at boiler pressure, and are surrounded with the low-pressure receiver steam, which becomes superheated in traversing the length of the receiver some 30° or 40°, varying according to the load on the engine. This jacket is very efficient and quite cheap. An advantage of the internal jacket is that the radiation is reduced. While theoretically we may believe it is a good thing to jacket the barrel of the low-pressure cylinder, practically we could not believe it because it is so unsightly in appearance, and the difficulty of making and maintaining it is so great.

Prof. R. H. Thurston.—I would like to ask a question before making any remarks on the paper. I notice that in the plates on pages 386, 387 and 388, the observations which are entered on those plates are scattered over the plates pretty generally and have no special relation, apparently, in sequence or location to the datum curves. I wish to ask if that is intended.

Prof. Peabody.—The scattering of the points is apparent only. That is, in order to avoid making an indefinite number of diagrams, several series of points have been plotted on the same diagram. While there are some individual points which have not very much meaning as yet, wherever there are a series of points I think it will be found that a provisional curve may be drawn which will have the same form as those drawn for the first and second series.

Prof. Thurston.—I see why I was puzzled. But I cannot see that curves could be drawn which would be smooth enough to give us anything at all. I am entirely at a loss in making deductions from data on those plates.

Referring to the statement in the text, that it makes very little difference where the steam-jacket is placed, I think that ought to be qualified somewhat, because, although I have no doubt that the understanding of the writer is correct, that it makes comparatively little difference whether the jacket is placed on the intermediate or the low-pressure cylinder, I imagine it does make a great difference whether it is placed on the high-pressure or the intermediate. Again, I imagine, as the last speaker suggested, that it would make a great difference whether it was on the heads or on the barrel. I presume the jacketing of the large cylinder might be of great service. But, as Professor Peabody suggested, it may result in the transference of too much heat into the cylinder, and the work be overdone.

This work is exceedingly interesting, and I asked these questions not in a spirit of criticism at all, but in the hope that we shall have very complete work at some future time and fully satisfactory results.

I would second Professor Jacobus's suggestion that a heat balance be made, and also that the experiments be made of somewhat longer duration, so that there could be no question as to the mean value of resultant data.

Prof. Peabody.—There is one point raised by Professor Jacobus which is answered quite fully in the paper. I want now to confirm the statements made there. I did not make those tests myself, and I have no personal interest in them further than comes from my connection with the school. They were made under the direction of the gentleman whose name appears with mine. I have studied a great many engine tests and have become quite ready to reject any test, for sufficient reason, from any source whatsoever, without the slightest regard to who made it or how much time it took. I want now to say that of all the tests I have studied I have never seen a series so satisfactory as those in group 1 and group 2 of the tests reported here.

I want to say further, that I am ready not only to believe myself, but to request others to believe, that the observations were entirely satisfactory. As stated in the paper, we have a sufficient number of instructors, so that anybody who does any work

at all is carefully watched. There are four men in charge of the work on this engine, who could themselves make that whole test and get it right, or any three of them could do so. They watch the whole work carefully from beginning to end. Every indicator diagram is inspected as it comes from the engine, and all of the measurements are carefully reviewed. All the calculations for all these tests are made by the instructing force and are known to be correct. Our students also make all the calculations, which must agree with those made by the instructing force. Now I believe, not only that these are conditions which will give us good results, but that we very seldom are able to get better conditions. I know, from sad experience, that students' work, when left to themselves, is apt to be entirely unreliable. But the work reported in this paper is not, in one sense, students' work, but the work of the instructors, since they are responsible for its accuracy and correctness.

As to the length of time, I know that an hour is long enough. We make five-minute observations, and I would venture to say that a quarter of an hour, or the hour divided into four quarters, would give tests which would give substantially the same results as these one-hour tests give.

Then as to the heat balance. Last year four such tests were reported to this Society. I would like to invite any one to make a calculation, not for these 42 tests, but for 4 of them. Our full instructing force would not be able to make such calculations for all. My belief in the necessity and advantage of the heat balance, or Hirn's analysis, is by no means so strong as it was when I first learned it. It cannot be considered a theory; it is only a way of trying to trace the heat from one end of the engine to the other. But, after all, the thing we have to determine is the quantity of heat that the engine uses, and I am quite sure that in these determinations the work is entirely reliable. Further, I do not believe it would be possible to get such curves as we have if it were not reliable.

Too much stress should not be placed on the advantage of using a cut-off at 30% of the stroke, our object being merely to show that we have found the minimum. It is true that a considerable variation of power produces only a small variation of economy, as is pointed out by Mr. Rockwood.

Our engine has the low-pressure cylinder jacketed on both the heads and the barrel; and we propose eventually to make tests,

jacketing the heads only, and the barrels only. I think I have in the course of these remarks answered the questions raised by Professor Thurston.

Prof. Jacobus.—The balance of heat referred to is not Hirn's analysis. It is based simply on the fact that the heat carried away by the exhaust, plus the equivalent of the work done by the engine, is equal to the heat in the entering steam, less a small amount due to losses by radiation.

Mr. Rockwood has just given us a practical example of this method, in his discussion of Professor Carpenter's paper.

*Prof. C. H. Peabody.**—In reviewing the discussion of this paper, I find that I inadvertently omitted to reply to Professor Jacobus's suggestion that it is unwise to draw deductions with regard to the effect of the use of the jacket; I certainly agree that final conclusions cannot be drawn from a series of tests which are confessedly incomplete, and yet I am sure that a careful examination of these tests will show that there is a material gain from the use of jackets on this engine, and venture to predict that our final results will show that 10% is not seriously in error. While I am ready to admit that the final word on jacketing has not been said, I cannot admit that Professor Jacobus's reference to the exceedingly good result of our engine test, reported in *The Engineer*, August 26, 1892, has much bearing on the subject. It is the hap-hazard comparison of isolated tests on different engines, under different conditions, to solve special problems, which leads to dispute and confusion. I want also to repeat again the absolute necessity of using the scientific unit of heat for the basis of comparison in the discussion of the problem of jacketing, instead of the elastic unit—pounds of steam per horse-power per hour.

Even the modified form of heat balance referred to by Professor Jacobus in his last remarks involves considerably more labor and inconvenience in making a test, and though it does give more weight to isolated tests, or a small group of tests, it does not appear to me to be necessary for tests made under the extremely favorable conditions found in our laboratory; moreover, the tests 10, 11, 12, and 15 were analyzed by Hirn's method with very satisfactory results, and may be considered to give such corroborative weight to the general accuracy of the methods employed as that analysis always indicates.

* Author's Closure under the Rules.

DXXII.*

A NEW GRADUATING STEAM RADIATOR.

BY JOHN T. HAWKINS, TAUNTON, MASS.

(Member of the Society.)

SOME of the most serious objections to steam heating by direct radiation, as now effected—particularly in residence buildings and similar situations—are too well known to require more than passing notice.

The impossibility of adjusting the heating effect of the ordinary steam radiator to changes in the temperature of the outer air is probably the greatest objection to that system; the facility with which this adjustment is effected in the hot-water system constituting the principal advantage which the latter possesses over the former; while the simplicity and perfection with which the combustion in the furnace is automatically regulated in the steam system gives it an equally decided advantage over the hot-water system; to say nothing of the greater first cost of the latter.

In direct radiators, located in residences, offices, and similar places, there is much annoyance and often no little damage, or both, from both systems, resulting from leakage through the stuffing-boxes of inlet or outlet valves, or both, or through that more prolific source of annoyance, the air-valve; whether the so-called automatic or the simple pet-cock, located in the ordinary steam radiator, as they almost invariably are, some distance below a level which the water of condensation is liable to reach in case of defective closing of inlet or outlet valves, or the leaking of these valves themselves when closed as tightly as may be; or, as the writer has more than once experienced in his own residence, by the furnace attendant neglecting to shut off the boiler feed, water entering the boiler under the city pressure until all the radiators in the house to the top story had become filled to the top.

* Presented at the New York meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

In the hot-water systems, one of the dangers is that of an isolated radiator becoming subjected to freezing temperatures, and, as a consequence, a rupture and leak which results in more or less damage to the premises.

In designing the apparatus shown in the illustrations it has been the object of the writer to avoid each of the objections named, by producing a steam radiator which may be regulated to any degree of heating effect at will; one that will have absolutely no openings to the air of any kind below the highest possible level of water in it; one which will render the use of an automatic air-valve unnecessary, by automatically expelling or excluding the air from itself when shut off, and preclude the possibility of freezing so long as fire is kept under the boiler, whether the given radiator be isolated in heating effect from the others or not.

As shown in the illustration, also, it has been attempted to produce a general arrangement or construction of radiator which will be, for a given radiating surface, as cheaply made as the cheapest form of steam radiator for equivalent use now on the market, if not cheaper than any.

The construction illustrated is such, also, as to contribute a minimum volume of water or steam space, in order that desired changes in graduation of the heating effect may be accomplished with reasonable quickness by the filling up from condensation, as hereafter explained. This is a necessary feature in this plan; it may, however, be observed in cast-iron or other constructions quite as easily.

The heating effect is graduated by varying the opening for the water discharge—which is by no means original with the writer, except as to the manner of effecting it—and providing for automatically preserving such level of water of condensation as may be decided on. When set for any particular amount of heating effect, the water level cannot vary except within small limits, as it may be affected by local and immediate changes in the temperature of the air of the room. This feature the writer believes to be entirely original with him.

Of course, it is understood that in such an apparatus, if it be kept partially filled with water, this water will cool down because it will not conduct the heat of the steam downward—the steam being in contact with it at the top only—and will thereafter radiate but little heat.

Fig. 156.

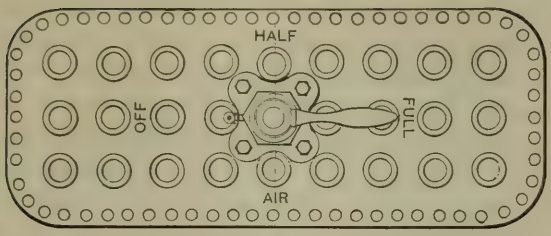


Fig. 158.

Fig. 155.

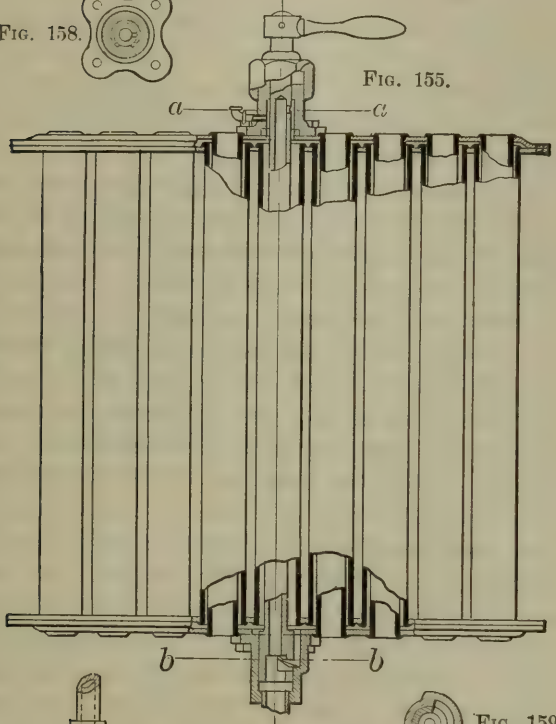
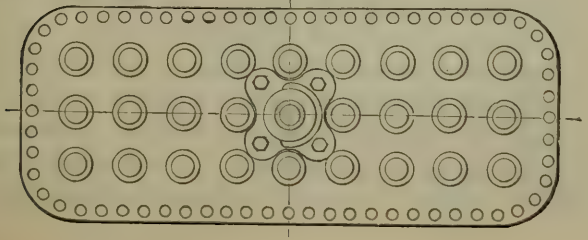


Fig. 160.

Fig. 159.

Fig. 157.



To shut off the heating effect altogether the water discharge is entirely closed and the radiator allowed to fill entirely with the water of condensation—which, owing to the small volume of water space, will quickly occur—in which case, of course, there is no chance for the accumulation of air within it as it cools off; so that, when turned on again, no discharge of air becomes necessary, and nothing more than the ordinary pet-cock is required for use—and this only when starting up the system—placed above the highest possible level which the water can attain; and this cock being always kept closed, whether the radiator is in or out of use, no leakage can take place through it.

In the illustrations, Fig. 155 is a side elevation, partly in section through the centre row of tubes; Fig. 156 is a top view, and Fig. 157 a bottom view. Fig. 158 is a horizontal section through the upper bonnet at the line *a*, *a*, Fig. 155; and Fig. 159 is a similar section through the lower bonnet at line *b*, *b*. Fig. 160 is a side elevation of the valve end of the central tube. In the construction shown, the apparatus is made up of a pair of boiler-iron heads at the top and bottom, into which the pairs of tubes—inner and outer—are expanded after the manner of boiler tubes, the steam and water occupying the narrow spaces between the pairs of heads and between the inner and outer tubes. This gives a very large amount of air-heating surface and a small volume of steam or water space. The vertical inside tubes, acting as flues, constitute the most effective kind of air-heating surface.

Secured to the upper head is a bonnet, provided with the customary stuffing-box. Through this stuffing-box passes the closed end of a small central tube, made of brass or other highly expansible alloy or metal. This tube has secured to its upper end a handle, by means of which it may be rotated. This brass tube also has a small opening in the side near the top of the tubular part, opening into and near the top of the chamber within the bonnet. At the base of the bonnet the brass tube is provided with a collar, fitting in a recess between the base of the bonnet and the top of the upper head, for the purpose of fixing the position vertically of the tube, or, rather, of its upper end. This collar is perforated with a number of small holes, as seen in Figs. 155 and 158, through which communication is maintained between the chamber of the bonnet and the steam space of the radiator. A small pipe enters the bonnet at the

left, Fig. 155, to which the ordinary pet-cock may be attached at a level above the top of the bonnet chamber, for the discharge of air as above explained. The central brass tube passes down inside the central radiating tube of the apparatus, in this case taking the place of one of the inner flue tubes. Its lower end is enlarged into a cylindrical valve fitting the inside of another bonnet secured to the bottom head, except for a part of its depth, where the bonnet is chambered out to a larger diameter for nearly half its circumference, to permit the entrance of water to and through the valve. The opening in the valve is helical in form at the top, and the lower limit of the bonnet chamber has a corresponding helical form, so that as the tube is rotated, and with it the valve at its end, the opening from the bonnet chamber to the interior of the valve or tube may be wholly or partially closed. A variation in the area of this opening will also occur for any rotary position of the valve by an elongation or contraction of the valve tube, as suspended from the collar under the upper bonnet. The different positions of the handle by means of which the valve tube is rotated, corresponding to the conditions of opening, are indicated on the upper head, Fig. 156, by the words "Full," "Half," and "Off."

It will be seen in Fig. 158 that the bonnet chamber does not entirely surround the tube, but that an abutment of about one quarter of its circumference fits against the tube, so that, when the handle is placed in the position marked "Air" on the upper head, the opening in the side of the valve tube will be closed by this abutment, thus shutting off communication between the interior of the tube and the steam space of the radiator.

Into the lower end of the bottom bonnet enters the pipe which leads to the steam space of the boiler, as in the ordinary one-pipe work; which in this system is preferable, and, as we know, the cheaper. It may, however, be readily constructed on the two-pipe system, if desired.

The operation is as follows: When fire is first started in the boiler and the whole system of pipes and radiators is filled with air, the handle is placed in the position marked "Air," in which case the passage for the discharge of the water of condensation at the bottom is at about half open, and the steam enters through it only, as it cannot enter through the top opening in the valve tube, this opening being closed by the abutment in the upper bonnet chamber. With the pet-cock open,

the steam entering at the bottom will expel the air through it. With the air expelled the pet-cock is closed and need not be again opened until the whole system, including the boiler, is allowed to become cold. To run the radiator in full heating effect the handle is placed at "Full," the steam then enters the radiator at the top, through the opening in the side of the valve tube, the valve opening at the bottom serving only for water discharge. This construction obviates one of the greatest objections to one-pipe work, that of having steam entering and water passing out simultaneously at the same horizontal opening whenever any considerable accumulation of water obtains within the apparatus; and this is very often, in most cases.

To graduate the heating effect, the handle is moved into position such that the opening for water discharge will be insufficient to dispose of the amount condensed; in which case the radiator will begin to fill and partially to cool off. As it does so, however, the partial cooling of the lower part of the brass valve tube will operate to contract it and thus slightly enlarge the discharge opening beyond what it was set at, and arrest the rise of the water level at some point for any given position of the handle which will not permit of the full discharge, and thus maintain the water level at some practically fixed point for any position. Conversely, if the radiator has been shut off wholly or partially, and a greater heating effect is desired, the handle is rotated into a position to enlarge the discharge opening, when the falling water level exposes to the heat of the steam a greater length of the brass valve tube, causing it to become slightly elongated, and thus slightly close the discharge opening, arrest the falling water level and maintain it at some lower point; and similarly for any position of the handle. In this way the water level, and consequently the heating effect of the radiator, may be adjusted to be automatically maintained at any desired degree between being entirely shut off and on in full effect.

With the radiator entirely filled the level of the water will reach the opening in the side of the valve tube at the top, within the bonnet chamber, and only the small area of this chamber will be exposed to the heat of the steam. Under these conditions the condensation will be exceedingly small, and what steam does condense within the bonnet will find its way down through the valve tube back to the boiler.

It will be noted that, except in the case of the expulsion of

air, the steam has always free access to the interior spaces, either through the valve at the bottom or through the opening in the side of the valve tube at the top, the latter even when shut off from use, or when in partial effect, so that the interior of the brass valve tube is always in communication with the boiler; and the cracking noise resulting from the admixture of steam and water in the ordinary radiator is entirely avoided, by the steam always having free access to the upper surfaces of the water.

The interior of the valve tube being always filled with steam when the radiator is put out of use, so long as there is any steam pressure in the boiler above the zero point, this tube will be heated; and this heating of the single central brass tube will be sufficient to slightly warm and, by the circulation it will establish in the surrounding water, prevent freezing; at the same time it will be so small in amount as to have no perceptible effect in warming an apartment.

Of course, with this apparatus—as with any other, hot water or steam—when the fire is extinguished and the entire system put out of use for the season, the water is drained out of the whole series of pipes and radiators.

It will be seen that in this apparatus all possibility of water leakage at any point is avoided, since there are no valves, stuffing-boxes, or other openings below the highest possible water level; and even in the extreme case of filling the whole system, through the neglect of an attendant to shut off a high-pressure boiler feed, no other leak can occur than might escape through the single stuffing-box at the top of each radiator if improperly packed. But it is well known that leaks through the stuffing-boxes of the water-discharge valves in the ordinary two-pipe system rarely ever occur, and that it is almost invariably the steam stuffing-box that leaks; and this, being below the level of accumulated water in the ordinary radiator, gives as great trouble as though it was the water stuffing-box itself. The prolific source of leak, and consequent annoyance and damage in the present steam radiator, is through the air-valve, automatic or otherwise, unless, as some are, they are provided with an elaborate system of small pipes to drain off their drippings to the cellar. The writer has examined and tested a variety of automatic air-valves and has not found one which will not leak water when the radiator is full above the level at which it is

attached, or above the level of the opening in the valve for the escape of air. In this system the air-valve is practically dispensed with.

Owing to the lateness of the season at which the writer commenced the preparation of this paper, he has not found time out of his multifarious duties to procure reliable data as to the comparative cost of a radiator constructed on the general plan herein described, and covered in by some sufficiently ornamental grating work, for residences, offices, etc., as he had promised himself to do; that is, as compared with radiators as now constructed, principally of cast iron, for either one or two-pipe work. But it will be seen that the first cost of the valve tube and bonnets, if made as cheaply as they may be, will not be very greatly in excess of the system of valves required for two-pipe work; and certainly not greater than for such forms of the ordinary radiator as, by divided bases and a corresponding plurality of sets of valve, are intended to subserve something of the purpose for which this is designed, namely, a graduation of the heating effect.

In such a radiator as is shown, its effective radiating or air-heating surface will be so much greater for a given space occupied and its weight so much less for a given radiating effect that (taking into account cost of handling and transportation, etc.), without having had time to look closely into it, it is believed that, for an equal heating efficiency, radiators may be produced on this plan as cheaply as any now in use. This conclusion is not, however, at all definite or well settled.

It may perhaps not be amiss to point out that the operation of the apparatus requires no skill for its manipulation or adjustment, and ignorant attendants can hardly make any mistake with it, and certainly cannot do any damage. It may also be noted that the back-aching operation of opening and closing valves situated near the floor is avoided, often most vexatious when stuffing-boxes are packed or screwed up very tight, or a valve has become more or less jammed upon its seat. This feature in the ordinary radiator has been thought to be of sufficient importance to be the subject of a recent patent, which has been quite extensively advertised and illustrated, showing the lady of the house opening or closing these valves with her foot.

It may be mentioned also that in its construction it is not

at all necessary that either the valve at the bottom of the valve tube, or the closing of the opening at the top of this tube when expelling the air, should be tight. A slight leakage at the former will only affect the position at which the handle is to be placed for the maintenance of a given water level; and while expelling the air, so long as the free flow of steam through the opening at the top of the valve tube is pretty well obstructed, the freer entrance of it below will expel the air.

In such cases as the expense of it would admit, a glass water tube may be attached to one of the outer tubes, by means of which the level of the water in the radiator may always be observed, and thus serve as a guide to the manipulation of the adjustment; ordinarily, however, feeling of the tubes with the hand will serve as a sufficiently good guide.

The writer has had an experimental apparatus, on the general principles described, in operation in his own residence throughout the winter of 1891–2, and found it to work admirably, giving all needed relief from an overheated room in mild weather, while giving ample warmth when the thermometer ranged low. It also conclusively established its immunity from leakage when, upon a second occasion, the attendant upon the boiler forgot to shut off the boiler feed and filled every radiator in the house with water, this being the only one out of nineteen which was not discharging water pretty freely about the floors from the automatic air-valves, until the surplus water was drawn from the system through the boiler blow-off cock.

DISCUSSION.

Mr. J. Sellers Bancroft.—I would like to ask Mr. Hawkins if that air-valve is necessary at all; that is, will not the air be displaced by gravity?

Mr. Hawkins.—No, sir, it will not. This apparatus is best applied in what is called one-pipe work, in which the single pipe leads to the steam space of the boiler. It would appear, from ordinary reasoning, that any air accumulating in the radiator, with free opportunity to discharge itself through any bottom portion of it, would, from the fact that the air is the heavier, find itself ultimately inside the steam space of the boiler, but such is not the fact. We can produce what pipemen know as an air-lock in a radiator, which it is impossible to dispose of in any other way than to discharge it through some higher

opening in the radiator. It was a long while before I could settle in my mind the *rationale* of the discharge of the air from steam radiators—why we should—with an ordinary pet-cock placed in the extreme end pipe, tube, or loop as they are called, of a radiator; in one of a series only, another series at the back of it having no pet-cock in it—discharge the air out of this radiator completely by means of steam let in at the extreme lower opposite corner. It must be something like this: the steam in the first loop or tube in some way replaces the heavier air then into the next loop, and so on until the air is expelled from the whole series. I have done as follows with an ordinary horizontal coil running up 8 or 10 returns: I have had a pet-cock placed in the extreme upper part, filled the coil with air, and then allowed the steam to be admitted at the bottom and the whole to remain in that condition two or three days, with steam on the boiler all the time up to 10 or 12 pounds pressure, and there was not the slightest indication of the air changing places with the steam by passing out of the radiator or coil into the steam space of the boiler during that time, but the very moment I opened the pet-cock at the top of the coil the air would begin to pass out and it would quickly fill with steam. It may be that I shall make some further experiments in order to get at the true inwardness of this matter, which I think is a little obscure as yet.

Mr. Bancroft.—There is in use in the shops of Wm. Sellers & Co. (Incorporated) an overhead system of heating made up of manifold coils. Some of these coils are placed flat and some on edge, all having a slight fall for drainage. They are fed from one branched main and discharge into one branched drain pipe. There are no valves on the system except the main admission valve, and no air-cocks on it anywhere. The steam enters at the highest point and passes regularly through by gravity. There has never been any difficulty whatever with its operation.

Mr. Hawkins.—I have never seen any system which did not have some provision for expulsion of the air.

Mr. Bancroft.—I would state that our system is supplied by exhaust steam. The back-pressure is never more than 1 pound. No attention is required further than turning the steam on or off. It takes care of itself and has been in use for two winters.

Mr. Jesse M. Smith.—It seems to me this question is largely

that of the size of the mains. I had to do with the heating of a very large car-works covering several acres of land and using exhaust steam entirely for that purpose, and where the steam pressure never went above 2 pounds. I took the precaution of putting in very large mains, so that the flow of steam had very little resistance, and there was no difficulty at all in heating the most extreme radiator in the building. The radiators were coiled pipes of short length. The radiators at the extreme end were sometimes air-bound, but they could be very readily freed of the air by a pet-cock at the end, and after the steam arrived at the pet-cock, then by closing it the circulation kept up even at partial vacuum. I have seen the whole system heated with a partial vacuum of 2 pounds.

Mr. Jos. C. Platt.—I would like to ask Mr. Hawkins if I understand this operation fully and correctly. Take a building in the fall of the year, when you have had no fire in the boiler and no steam in the pipes. You have the entire system filled with air. You start your fire at a time of year when you need a comparatively small amount of radiating surface to heat the building. Steam passes up through the radiators, with this valve set perhaps at half or quarter—assume for the moment that it is set at a quarter—your radiator, after the air has escaped, would then fill with water up to three-quarters full and leave the upper quarter full of steam and the lower three-quarters full of water. Is that about the practical operation?

Mr. Hawkins.—Not exactly. When first starting up the system it is necessary to discharge the air not only from the radiators, but from the pipes, the steam space of the boiler, and the whole system; and in order to do that you would put the handle in the position marked air, in which case the opening of the valve for discharging the water is at about one-half—quite sufficient to allow a very free access of steam at the bottom, and the access of steam to the radiator above being closed and the pet-cock open, the air will be discharged; as soon as steam appears at the pet-cock you shut it off and set the handle at whatever position you want. The radiator will then fill up with water to the required level.

Mr. J. C. Platt.—Assuming that you have a radiator filled up three-quarters full of water, and that one-quarter gives a sufficient amount of heating surface to heat the apartment, then your radiator will continue to stand, if I am right, with that amount

of water in it until the position of the handle is changed. Assume for a moment a house of a dozen rooms and assume an ordinary boiler such as is in common use, will it not be true that if mild weather changes to severe cold weather, and you go around to all of those valves and open them wide, you will then discharge a volume of water equal to three-fourths of the contents of each radiator back into your boiler, and will you not in such case run a great risk of flooding your boiler and filling it more than full? In this way the occupants of the room do precisely what in the instance cited here the careless attendants did.

In many cases an automatic feed valve is attached to the boiler to keep the water level up to its proper condition. I have known of some such cases. I remember one, particularly, which I have in mind and which will work, or ought to work, when you want more water, but it will not draw off an excess of water. Will not difficulty arise in such a case, and how would you remove it?

Mr. Hawkins.—I can answer that by reading a portion of the paper:

"The construction illustrated is such, also, as to contribute a minimum volume of water or steam space, in order that desired changes in graduation of the heating effect may be accomplished with reasonable quickness by the filling up from condensation, as hereafter explained. This is a necessary feature in this plan."

I might have gone on and elaborated more, perhaps, as to why it is otherwise so necessary a feature. If all the radiators in a system of this kind should be full—that is, all shut off—and a sudden change to colder weather comes on, so that you have to turn them all on in full heating effect, you would discharge a considerable quantity into the boiler if the radiators contained any considerable quantity as compared with the volume of water in the boiler, or the area of its water level. But the volume of water in these radiators is intended to be so small that the discharge of their contents into the boiler will not materially affect the water-level therein; and this may be as small as you like, not to have capillary action between the inner and outer tubes.

Mr. A. C. Walworth.—I recognize many excellences in this radiator, but I presume these papers are brought here so that

the weak points as well as the strong ones may be discussed. It is evident that one of the chief objections to this radiator is the one which has been named by Mr. Platt. I do not know how much water one radiator contains, but I can see very readily that in the experiments the gentleman made in his own house, where he had only one radiator, that radiator affected the water-line very little. But with a boiler containing say thirty gallons of water, considerable variation would be made in the water gauge by one gallon, so that the variation of the large number of gallons from all the radiators would make a very large variation in the water-level of the boiler, which in most boilers would interfere with its efficiency; either flooding it or else leading to low water and burning out. I think the true way to get rid of the air in this radiator would be by an automatic air-valve connected with an air pipe or waste pipe going to some suitable receptacle in the basement, so that the water would be taken care of. I think myself that is the only proper way to put in the air-valves of a steam apparatus. There is always more or less risk of leaking unless you have a waste pipe running to the basement.

Another objection to this radiator, I think, would be its expense. Radiators have of late been reduced to a very low price: the radiator of commerce is placed on the market at about 3 cents a pound; that is, with a surface of about 7 pounds to the foot, some perhaps lighter than that, and these radiators are placed on the market at from 21 to 24 cents a square foot in large quantities, while indirect radiators are placed as low as $2\frac{1}{4}$ cents a pound, which you see leaves a very small margin for profit, and a very small margin for going into complications of mechanical construction of this kind. If there are 700 square feet in a house, you see an addition of a dollar or even of 50 cents a foot makes a large item, and we find that people who are purchasing apparatus look after every dollar as if it was of vital importance.

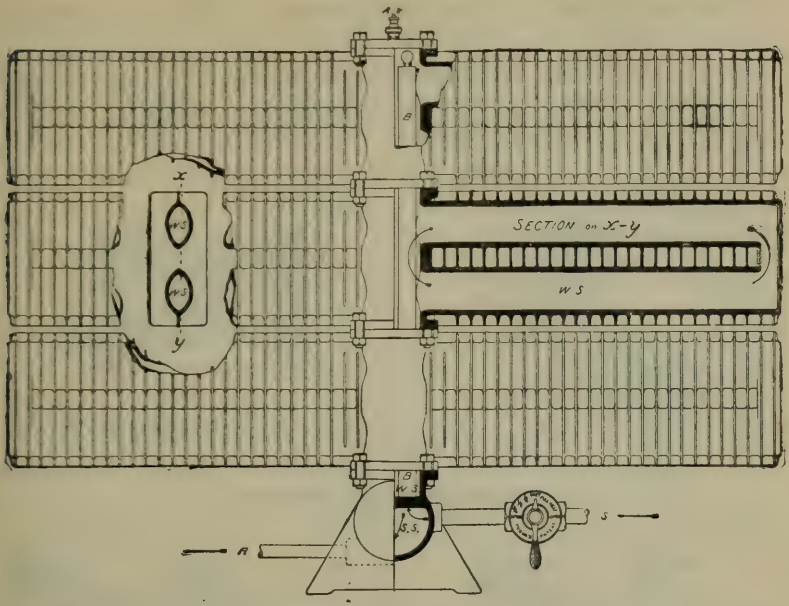
It might be interesting to mention some of the other devices used to control the heat of the radiator. It has always been urged as one of the excellences of the hot-water apparatus that the temperature of its surface can be carried at from 100° to 240° or 250° Fahr., if you work it under pressure, while steam radiators have very little variation. One way of controlling a steam radiator was illustrated by a radiator I saw in use where a lady

had put a petticoat around it, a circular radiator, with this petticoat reaching the ground on all sides, and provided with strings and loops so that it could be pulled up or let down exactly as a lady raises her skirts in crossing the street. Radiators have been devised, also, which were placed in a casing with a curtain in front. I have constructed radiators of that kind myself. Any one who has not even intelligence enough to manipulate a steam valve will know enough to raise or lower a curtain in front of the radiator. In Mr. John H. Mills's system he applies a radiator to the riser with one steam valve, and one air-valve opposite. Now if he has steam at 3 pounds pressure in the riser and keeps this air-valve closed, the steam in entering will drive out the air, and will compress the air toward the end where the air-valve is located. Or if you have perhaps 7 pounds, it would compress it still more. By opening the air-valve you let in steam and let out air at the farther point, and by leaving it open until the steam expels all the air you can fill the radiator with steam.

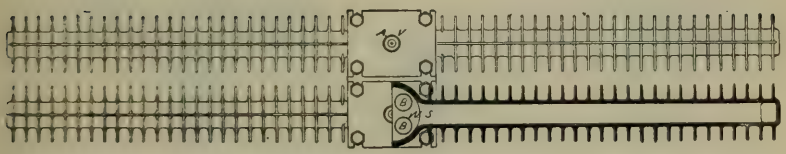
Another system of controlling the radiation is by using a radiator constantly full of water and heating that water by steam, by transferring the heat of the steam pipe to the water pipe. That system was used in Germany by Schäffer & Walcker, Berlin, quite a number of years ago, and it was also used by Mr. Fairbanks, who makes the scales, at St. Johnsbury. The German firm also made a radiator with a variable water-level. A very good type of a "steam-water" radiator is one I am now placing in the New Boston Public Library. It was devised by Mr. Fred. Tudor.

The radiator (Figs. 192 and 193) is mounted on a base containing in its lower part a steam-chamber analogous to a steam radiator base, and, in its upper part, an open water chamber to which the radiator itself is bolted, and of which it is an extension: from the steam space marked *S.S.*, up through the water space marked *W. S.*, extend from one to four vertical brass radiator tubes (*B.B.*), open at the top, at which point the air is expelled through the automatic air-valve *A. V.*

On the supply pipe near the radiator is the fractional valve, shown in detail in the second illustration, while *R* is the return pipe which leads to a water-seal not under pressure, the return water being pumped back to the boilers. The operation of the radiator is as follows: steam being admitted through the frac-



ELEVATION; PART IN SECTION.



PLAN; PART IN SECTION.

HOT WATER RADIATOR

HEATED BY STEAM.

A V AIR VALVE
S S STEAM SPACE
W S WATER SPACE

0 6 12 18 24
Scale of Inches.

Designed by
FREDERIC TUDOR.

BRASS TUBE, B.
SUPPLY, S.
RETURN, R.
33 of 1m.

FIG. 192.

tional valve, it fills the steam radiator, driving the air upward before it, and out at the air-valve; it then fills the water radiator, which, having no outlet at the bottom, becomes gradually filled with the water of condensation as high as the top of

the vertical radiator tubes, and becomes, in fact, a hot-water radiator.

The temperature of the water in this radiator, and consequently of its radiating surface, depends very evidently on the amount of steam admitted to the internal steam radiator,

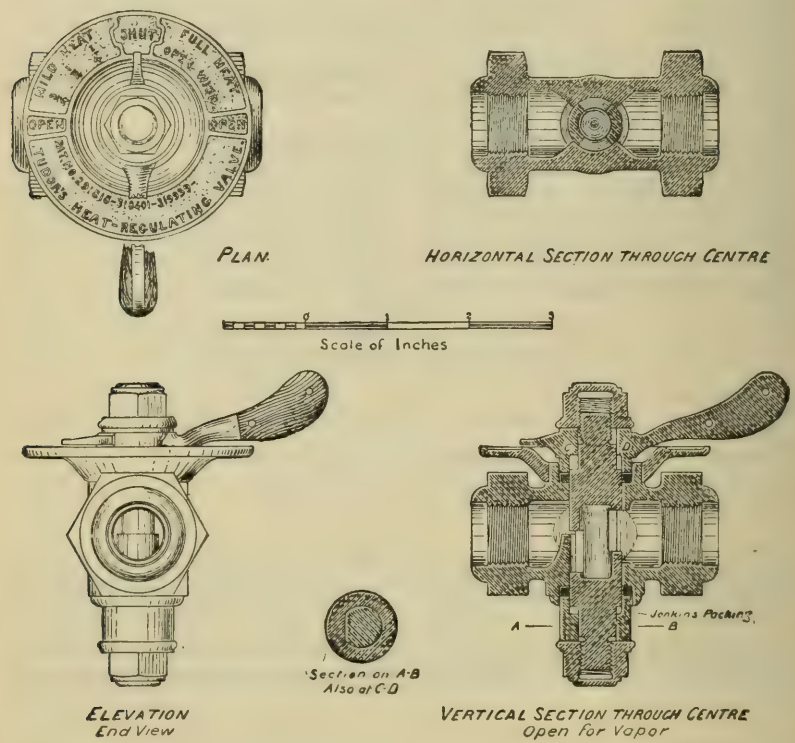


FIG. 193.

through its fractional valve. As a matter of observation, with steam-pressure of 5 lbs., the water is raised to 196° Fahr., but if the steam is throttled by the fractional valve at the $\frac{1}{4}$ mark, this water is warmed to 95°, thus placing a wide range of temperature under the control of the motion of the handle of said valve, which can be set instantly, without exertion or loss of time. In

each case the valve admits just enough thermal units into the radiator to raise it to the temperature desired, and maintain it against loss by radiation from its surface.

In the fractional valve, if the index is turned to the right to "full heat, open," the construction of the valve is such that there is a free passage through it. This is the position of the valve for starting the radiator or in warming up a cold room. If the index is turned to the left, to any of the points marked "mild heat," the valve is more or less throttled according to the fraction marked on the dial.

With Mr. Hawkins's radiator in dwelling houses, I should be a little afraid of its being left, in some rooms, full of water, and then neglected, and freezing in cold weather. Of course, that is an objection which would apply to any hot-water radiator when shut off, and is not so serious a one as the high cost of any radiator of this type. I think exemplification of a radiator for transferring steam heat to hot-water heat, as used in the New Boston Public Library, is one of the best of the kind I have seen, and it is working practically well.

Mr. Breckenridge.—Much of what I intended to say has been presented by the preceding speaker, and I would simply add that Professor Richards, of the Massachusetts Institute of Technology, has, I understand, been making a good many experiments with getting air out of radiators and determining the best place to put an air-valve, and any who are interested may find it well to refer to those experiments.

The cost of Mr. Hawkins's radiator is quite considerable, and it is a question whether it could be placed on the market to advantage. We have operated a radiator on the same system in my office for some time, that is, with an ordinary pipe coil, and if we wanted to have it get cool slowly we would shut the discharge valve and not let the water out so fast. The difficulty is, that we sometimes have a good deal of music in the office, and the question is as to whether Mr. Hawkins would guarantee that his radiator would play any desired tune.

Mr. Samuel M. Green.—In relation to what the gentleman has said of the system of heating mills by overhead piping, I would submit the following: In a mill four stories high, heated in this way, with the drips returning into what is known as a receiver pump, I found that air in the pipes would prevent a free circulation even with a pressure as high as fifty pounds, and that

steam would not pass through all the pipes in four hours. By placing an automatic air-valve on the receiver the circulation was easily established within ten minutes.

Mr. Hawkins.—I think the last speaker misapprehends the construction of this radiator when he talks of music. I never heard any in it. One of the principal objects I had was to avoid the music usually attending steam radiators. The steam being admitted at the top of the radiator at all times, we never have that antagonism between the water passing out and the steam passing in, which gives rise to the music. With reference to the flooding of the boiler, I wish to say one or two words further. I may point out that it is a desirable precaution. When we have a series of radiators in the house which have been shut off and thus filled entirely full, holding each but a small cubic content of water, and we are going to turn them all on again, which is an extreme case, we are going to require a little more water in the boiler than was previously necessary, and it is a very good thing to put it in at that time, because the automatic damper is going to start the fire up and maintain it under the most severe conditions. If it had been objected that allowing the radiators to fill by condensation would lower the water-level in the boiler, there would be greater pertinency in it; but in this case it is nearly as inconsequential, from the fact that at such a time the automatic regulation of the combustion establishes and maintains such a state of things that slightly lower water would be attended with no danger whatever.

The fact is, that in the proposed system the two extreme cases of all radiators shut off or in full force, themselves provide by a slight variation in the boiler water-level for meeting the changed condition in the furnace in the best way and in the safest direction. The main thing to be borne in mind, however, is that we may make the quantity of water, held by one of these radiators, so small compared with the capacity of the boiler to receive it, as to be of no consequence whatever.

I have an ordinary tubular boiler in my cellar, and it receives all the discharge from 19 Bundy radiators in the house. I do not think that with the Bundy radiator their whole contents would raise the water-level over 1 inch, and as I should expect to have not more than $\frac{1}{10}$ the water volume of the Bundy for a given radiating surface, it becomes a matter of no consequence.

With reference to the method of regulating by means of an

air-lock, I have experimented considerably with that myself, and I or any engineer can take an ordinary radiator and quite satisfy himself in regulating the temperature of the room by that means, provided he is satisfied to get it in one direction only; but such regulation cannot be had in the other direction. It cannot be gotten in cooling off, because all we can do is to permit more or less air already in to escape while increasing heat. We must get the radiator heated up and allow it to fill with air again before we can regulate to cool off. That is only one objection to the air-lock method of adjustment. Another, and the most insuperable, is that it requires a skilled somebody's attention. In the radiator I have designed, you will see that the regulation of the temperature is not automatic, but is automatically maintained. If you are a little too cold and want it warmer, you have nothing more to do than to move the handle in the direction of being wider open, and the water-level will be automatically maintained at a lower level. With reference to the cost, I have realized the fact that, possibly, this radiator is going to be a little too expensive to be put on the market in competition with the very cheapest devices now made. But I do expect to make it so good that people will say, It comes a little higher, but we must have it.

I will call Mr. Walworth's attention to the cost of what he has shown us; that in comparison with the system which he has here explained, I will guarantee to say that I will supply a residence with a system of radiators which will be much more easily and certainly regulated, and will be as effective to warm the house fully, and very much cheaper than the system he describes can be supplied.

Mr. Walworth.—The system described is not a cheap system.

Mr. Geo. A. Hill.—While this device seems to possess considerable merit, it belongs to the class of inventions which rarely become of practical importance.

This is evident when we consider that:

First. It will prove expensive to manufacture, since it will fail to operate unless made with a certain amount of care, far more than the ordinary radiator requires, and this remains true even if you introduce the element of perfect control of the heat in the place to be heated.

Second. It is doubtful if it will continue to operate satisfactorily after the lapse of a few years.

Third. If we consider that ventilation is of as much importance as heating, it is a move in the wrong direction, since it permits of a graduation of the heat of a room, which is as easily accomplished as by direct radiation, giving an excuse for abandoning indirect radiation with its accompaniment of warmed fresh air. To make this more plain, we consider that we have two general classes of heating, which we may call, roughly, office buildings, or those that are occupied about eight hours per day, with the number of persons per thousand cubic feet limited to about five, all heat being shut off during the night, and heat required quickly in the mornings; and dwellings, or those which are either occupied by many more people, and require to be maintained at a uniform temperature, without causing trouble to the inmates, and, in fact, without their knowledge, or where the client desires these results for his own convenience. We can meet the requirements of the first class most readily by placing two radiators in each place to be heated, making the capacity of each 60% of that required for the place by good practice. Then, on opening the place in the morning, it can be readily and quickly warmed to the desired temperature by the use of both radiators, and then kept nearly right by using only one. The same result can be had by using a double radiator and two sets of valves.

If there is an opportunity to place exhausting flues in the walls they should be so placed, and then the radiators made with a box base, and of the flue type with the base connected with the outer air. Then we can start the warming, by warming the air of the room over and over again, until the desired temperature is reached, and then it can be maintained, and fresh warmed air constantly be introduced. Such an arrangement affords excellent ventilation, and keeps in service only the amount of surface necessary to do the work, while it permits of the regulation of the heat to any desired extent.

If the problem is the heating of a dwelling, theatre, church, or other place which requires that there should be a considerable amount of warmed air constantly introduced, and the foul air as constantly removed, and that without the aid of the occupants, the best results in my opinion are to be had by means of indirect radiation. In this case all of the surface can be arranged around the boiler, as is done by some of the manufacturers of heating boilers, so that the fresh air will pass around the boiler as well as the radiators, saving a little of the waste heat of the

boiler. The coils may be of pipe or sections of any desired form, but should preferably be of the direct circulation type, so as to be used either for water or steam, and in two or more horizontal layers, so as to have several layers through which the air can pass, thus heating it to any desired point, and reducing the surface by cutting off layers. When the cost of finishing up the radiators and pipe, felting pipe, and general dissatisfaction due to imperfect control of heat, is equated against the slightly increased cost and the far more perfect ventilation which is secured, I think that the balance is in favor of the indirect plant.

The advantage of the method outlined, and the disadvantage of Mr. Hawkins's method, lies in the facility with which the temperature is regulated and a constant supply of fresh air delivered to the rooms.

While there are no doubt places where this form of radiator will prove to be just the thing, we should not lose sight of the fact that there will be enough work done which disregards the requirements of ventilation, and in the work that we do, that we so install our plants that both heat and ventilation will be secured.

The objection raised, that there would be danger of flooding the boiler in case of a sudden drop in temperature, is one which can be readily overcome by using an automatic furnace supply and placing a trap in the ash pit, or other place, where the radiation will be reduced to a minimum, connecting with the boiler through a fair-sized pipe at the proper water-line. This will waste a certain amount of water, but not enough to be of consequence.

*Mr. John T. Hawkins.**—To Mr. Bancroft I would reply, that the operation of his overhead coil supplied with steam at the top, verifies the operation of my apparatus, so long as the system is not allowed to cool off long enough to permit of the entrance of air to supply the vacuum which results from the condensation of the steam in such a case.

Mr. Smith's remarks corroborate what I have said in the paper as to the continued heating of such a radiator as mine when shut off and filled with water of condensation, even with the pressure of steam in the system below the atmosphere, as is often likely to occur at night. He also verifies its operation entirely so far as the expulsion or exclusion of air is concerned.

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* Author's Closure, under the Rules.

In reply to Mr. Walworth, and finally to the objections of the other speakers, whom Mr. Walworth is disposed to sustain, to the effect that the discharge of the contents of a series of these radiators at once into the boiler would be likely so far to raise the water-level therein as to interfere with its efficiency, I think that their acquaintance with radiators now in use has prevented them from properly appreciating the construction of this apparatus. To set this matter at rest, I will say that in the apparatus as illustrated in the paper—drawn therein to a scale of about 1 inch = 1 foot—we have an actual radiating surface equal to about 100 square feet; and as the efficiency of the interior flue-like tubes will be about $\frac{1}{2}$ greater than an equal exterior surface, it will have what is equivalent to about 125 square feet of the ordinary cast-iron apparatus with wholly exterior surface.

To the criticism that in my experiments, made with a single radiator in my house, I escape appreciation of what would be the effect if all the radiators in the house were constructed on my plan, a few simple figures will reply. I have in my house 19 direct radiators of the Bundy pattern, some of them very small, as in bath and other small rooms, but aggregating about 550 square feet of radiating surface; $4\frac{1}{2}$ such radiators as is shown in the paper would equal them in radiating efficiency. If the whole contents of $4\frac{1}{2}$ of them were discharged into the boiler at once—the extreme case for my house—it would add thereto less than $1\frac{1}{4}$ gallons as the radiators are designed, with $\frac{1}{32}''$ spaces between tubes and $\frac{1}{8}''$ between the heads—say 290 cubic inches. The boiler which supplies the 19 Bundy radiators is 8 feet long and 34 inches diameter—a liberal-sized one no doubt, which, however, I believe in in such places—and therefore has over 2,900 square inches area of water-level; consequently, the addition of the contents of all the radiators in my house on the proposed plan would raise the water-level about $\frac{1}{10}$ of an inch; and, conversely, would lower this level a like amount in shutting them all off and allowing them to fill with water at once, both results being had, as before pointed out, just when they are most desirable, as affecting the operations to follow at the boiler.

Again, he mistakes the principle on which this apparatus is constructed who thinks that "the true way to get rid of the air in this radiator would be by an automatic air-valve, connected with an air pipe or waste pipe going to some suitable receptacle

in the basement, so that the water would be taken care of." There can be absolutely no water to take care of in this apparatus. It needs no air-valve through which to expel air every time it is turned on from a cold state, previously obtained by the mere shutting off of the radiator from the system; because, being filled with water when shut off, there can be no air within it to expel; and it will be impossible for the contained water to escape at any point, for the reason that its level can never rise above the opening near the top of the valve tube; all condensation taking place above this point, within the bonnet, when the apparatus is full of water, finding its way through that opening and down through the valve tube and supply pipe to the boiler. This tube, therefore, together with the supply pipe, takes the place of Mr. Walworth's suggested drain piping and leads all surplus water, not only to the basement, but into the boiler itself, which is much more desirable.

The statement that "there is always more or less risk of leakage unless you have a waste pipe running to the basement" has no application to this apparatus. With the pet-cock in the upper bonnet closed, as is always the case after the apparatus, in common with the whole heating plant, is first put into operation, there is absolutely no possibility of water leakage.

As to comparative cost, I may give some approximate figures: I estimate that for a radiator equal to that shown in the paper—with 27 pairs of tubes, 3 inches outside diameter of the larger tube, and 30 inches long, it will have an actual radiating surface of about 100 square feet; and with these proportions may be made to weigh not to exceed 250 lbs.; and allowing that, owing to the flue-like construction of the inner tubes, its radiating efficiency will be fully equal to 125 square feet of the ordinary external surface. This would give for this form of radiator about 2 lbs. weight to 1 square foot of surface, or $\frac{2}{3}$ of the weight given by Mr. Walworth for the cheapest form of cast-iron direct radiator. If these are sold, as he says, as low as 3 cents per pound, or 21 cents per square foot of surface, my form of radiator may be sold at $\frac{7}{2}$ of 3 cents $= 10\frac{1}{2}$ cents per pound, and be as cheap; to say nothing of the less cost of transportation, handling, etc. In other words, my radiator at $10\frac{1}{2}$ cents per pound will sell for the equivalent of 21 cents per square foot of effective surface.

I am quite sure that even the smaller sizes—in which the cost of the central tube work is the same as for larger sizes—

could be sold at a good profit at 10½ cents per pound, and thus be as cheap as the cheapest, while larger sizes would be cheaper still. I think, moreover, that in present commercial radiators of cast iron there are more sold which weigh 10 lbs. to the square foot than less.

Misapprehension of the principles involved in this apparatus appears again when the objection is urged: "I should be a little afraid of its being left, in some rooms, full of water, and then neglected and freezing in cold weather."

As I have pointed out in the paper, communication between the interior of the valve tube—which runs through the entire length of the central radiating tube—and the boiler is never, and cannot be, shut off. Hence this single brass tube is always heated so long as there is steam kept in the boiler; and this will always be sufficient, through the circulation it must establish and maintain, to prevent freezing. When the fires are drawn, the whole system—as with any other—is to be drained.

Mr. Green's remarks agree with my experience as to the certainty of steam radiators getting air-bound at some time, or under some circumstances, unless provision is made for discharge of the air; and I think that Mr. Bancroft will sooner or later encounter that in the overhead system he describes, notwithstanding that the steam enters at the highest point, which is the most favorable condition.

To Mr. Hill's remarks, I may say that they are principally directed to the purpose of showing that the indirect is superior—as affected by the question of ventilation—to the direct system, to which latter my apparatus is necessarily confined. As, however, this question is not at issue here, and is hardly germane to the discussion, I may content myself with saying that, so far as the question of ventilation is concerned, if the direct system is properly planted, there is little left to say in favor of the indirect system as compared with it; while the greater cost, over the direct method, of heating so much, if not all of the air from the outside temperature to a temperature sufficient to give the room or rooms the desired temperature, even in the compound methods he describes, militates much against the indirect plan Quite as good ventilation—in fact, any amount which may be desired—may be had with a direct as well as with an indirect plant, if proper provision is made for it; and it requires no argument to prove that the coal bill will always be greater in any

indirect system for a given heating effect procured; and this is a far more serious matter, even, than the first cost of the plant.

To the objection that it will fail to operate "unless made with a certain amount of care," I can say that, inasmuch as there is no such thing as a tight valve in it, or required in it, the quality of workmanship required in its construction will be of a very ordinary kind. And for the same reason his second objection falls: mere wear can affect nothing more than to require a slightly different position of the adjusting handle for a given water-level or heating effect. There is nothing in the apparatus which requires nearly so much care as the common globe valve, either in manufacture or during use.

The suggestion to place two radiators in a room jointly equal to 120% of that required under a maximum demand, will make such an arrangement, with its double set of valves, piping, etc., not less than 25% or 30% more costly than a single radiator of sufficient capacity; while he can have but two grades of heating effect. In comparison with such an arrangement I can supply a cheaper plant for equal effect; have any desired graduation; freedom from the annoyance of air-valves; positive immunity from leakage and freezing; have but one handle to manipulate for all adjustments, and that in the easiest and most accessible position; in a word, an apparatus which provides against about all the annoyances and discomforts now attending the use of direct radiators; and the direct system would be much more largely used than is now the case—because of its superior cheapness in first cost, operation, and maintenance—but for the defects, annoyances, and discomforts which I have sought to overcome.

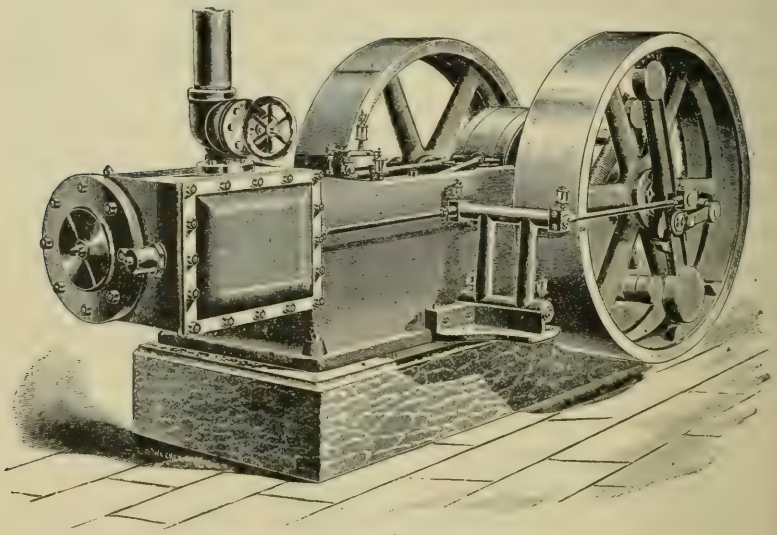
DXXIII.*

COMPARATIVE VARIATION IN ECONOMY WITH CHANGE OF LOAD, IN SIMPLE AND COMPOUND ENGINES. EFFECT OF STEAM-JACKETS ON HIGH-SPEED ENGINES.

BY R. C. CARPENTER, ITHACA, N. Y.

(Member of the Society.)

In a recent test of economy of engines working under different conditions, some results were obtained which it is believed



FRONT VIEW OF SINGLE CYLINDER ENGINE.

Fig. 167.

will not be without interest to the members of the Society, and they are here presented as briefly as possible.

* Presented at the New York meeting (November, 1892) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

The opportunity to make these tests was afforded by the courtesy of the J. H. McEwen Manufacturing Co., of Ridgway, Pa., and the tests were conducted by the writer personally, assisted by Mr. F. N. Bulkley, engineer in the mining department of the Thomson-Houston Electric Co. The engines tested were of the standard automatic type, with a fly-wheel governor of somewhat novel design, but yet very efficient in its action, as shown by the accompanying log of the tests. The preceding cut, Fig. 167, shows clearly the general form of the simple engine. The compound engine (not shown in drawing) was of the tandem type, with the high-pressure cylinder arranged in the usual manner outside the frame. The cylindrical or barrel portion of the high-pressure cylinder was jacketed, and connection made to the boiler in such a manner that steam of boiler-pressure could be supplied the jackets at pleasure. Tests were made with and without the jackets filled with steam. These tests are of interest as showing the effect of jacketing the cylinder-barrel on high-speed engines.

The following gives the dimensions of the engines tested :

TABLE OF DIMENSIONS.

	Simple Automatic.	Tandem Compound.	
Diameter of cylinder—inches	12	9	16
Length of stroke "	14	14	14
Diameter piston rod "	$1\frac{1}{2}$	$1\frac{7}{16}$	$2\frac{1}{2}$
Area piston, head end—square inches	113.1	63.62	199.43
" " crank " " "	111.2	62.00	196.15
Clearance as measured, per cent	8.75	12	9
Rev. of engine per minute	245	265	265
H. P. constant per lb. M. E. P. head	0.982	0.592	1.865
" " " " crank	0.952	0.577	1.835
Ratio of volumes in compound engine		1	3.12
" " " including clearance		1	3.03

CONSTANTS AND CORRECTIONS.

The valve of low-pressure cylinder was operated by a fixed eccentric set to cut-off at $37\frac{1}{2}$ per cent. of the stroke.

Arm of brake, used on compound engine, 5 feet 3 inches.

Correction to scale reading for weight of brake, 25 pounds.

Correction to gauge on steam boilers, —3 pounds.

Indicator springs used—simple engine, 40 pounds per inch ; compound engine, 80 lbs and $\begin{cases} 40 \\ 20 \end{cases}$ lbs. per inch

General Arrangement for the Test.—The general arrangement adopted for making the test is shown in Fig. 168.

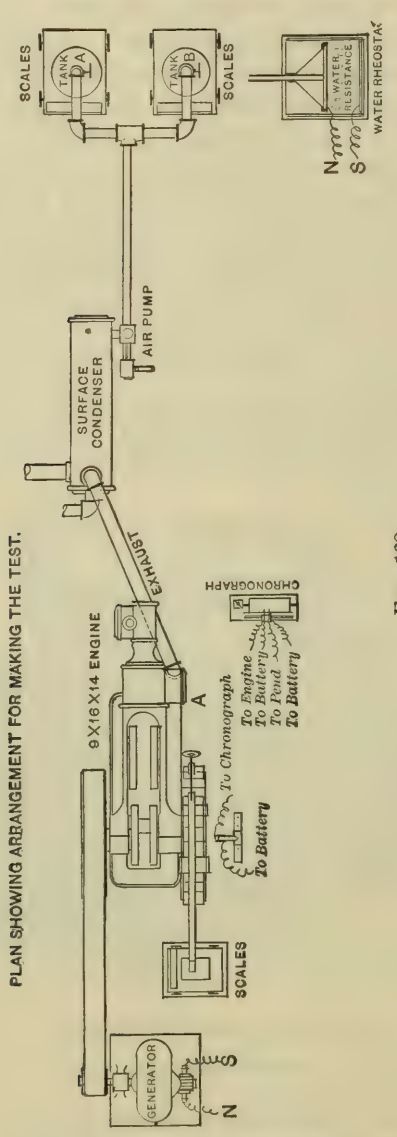


FIG. 168.

The engine to be tested was set on a heavy foundation at *A*, which was in close proximity to a boiler fired with natural gas. The exhaust from the engine was led to a surface condenser,

on a lower level and about twenty feet distant. An air-pump removed the condensed steam, and delivered it as required into either of two tanks standing on scales. The water for condensation was supplied from the city water-works.

The load during the test of the simple engine was obtained by driving a Thomson-Houston generator, arranged to deliver its current to a water rheostat designed by Mr. Bulkley.

The water rheostat consisted of a simple water-tight box nearly cubical, and four feet on each edge. A piece of boiler plate was securely fastened in a vertical position and connected to one of the poles of the generator; a similar piece of boiler plate was connected to the other pole, and arranged so that it could be moved by a wooden handle to a position any distance from the fixed plate. It was supported in a parallel position by means of guides.

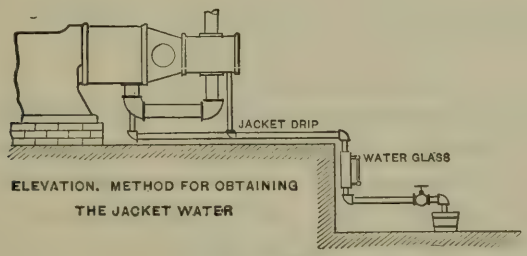


FIG 169.

In making the test the box was partly filled with water, some salt added, to increase the conductivity of the water, the current from the generator sent through the liquid, which made a resistance varying inversely as the distance between the iron plates. The electrical current was measured by a volt meter and ammeter, and from these readings the electrical horse power was determined. This load proved very satisfactory, as it was steady, and could be varied exactly to suit the requirements of the work. The general effect of a long run was to heat the water of the rheostat and apparently to remove finely divided particles of iron from the plates. This method of obtaining a load is perfectly safe with a generator of low voltage, but it would probably be attended with considerable risk and danger with currents of high intensity. In testing the compound engine an additional load was obtained by the use of a Prony brake, fitted to a special wheel with deep flanges, carried on one axle.

The general arrangement used in measuring the jacket-water is shown in Fig. 169 ; the water passed in drip-pipes to a slightly lower level, where it could be drawn off.

The water from the jackets was maintained at a constant level by aid of a water-column arranged as shown in the sketch, the water being drawn off slowly into a bucket, at such a rate as to maintain the level constant.

Apparatus Used in the Test.—The apparatus consisted of four Crosby indicators, in good condition, and of which the accuracy had been established by a careful calibration preceding the test. The vacuum gauge attached to the condenser was a mercury manometer, and of itself a standard. The steam gauge on boiler read three pounds too high. The engine speed was determined by a tachometer, belted to the engine shaft, and also occasionally by comparisons with a chronograph. The accuracy of the readings of the tachometer was thoroughly established before commencing the test, by hand counting, and by comparing with the results from the chronograph. The electrical instruments were standarized before the test.

The quality of the steam was determined by a throttling calorimeter constructed of pipe fittings, of similar form to that shown in a previous paper* before the Society and in a recent book by the author.† The quality was determined from readings of a thermometer. The calorimeter was inserted in a vertical pipe, close to the engine, and arranged to draw steam from all parts of the pipe.

The General Methods of Testing.—The general methods of testing involved the following determinations:

First, Determination of quality of entering steam, by a special throttling calorimeter; *second*, determination of pressure of entering steam by a calibrated pressure gauge; *third*, weighing of water of condensation from the engine and from the jackets. In testing the engine to find the duty when non-condensing, an attempt was made to secure the same conditions, by use of the condenser, as when freely exhausting into the air. In doing this, indicator diagrams were first taken with the engine exhausting freely into the air, then the condenser was attached, and the attempt made to run the air-pump so as to produce a vacuum just sufficient to overcome the extra resistance of the pipes in the

* Vol. XII., Paper CCCCLII.

† *Experimental Engineering.* N. Y.: J. Wiley & Son.

condenser. It was found that by setting an air-cock in the condenser there was no difficulty in maintaining the vacuum desired, by regulating the opening in the cock and the speed of the air-pump. A reading of the vacuum gauge of two inches was found to give the same back pressure as when the engine was freely exhausting in the air. A sample diagram taken in this condition is submitted. Fig. 178.

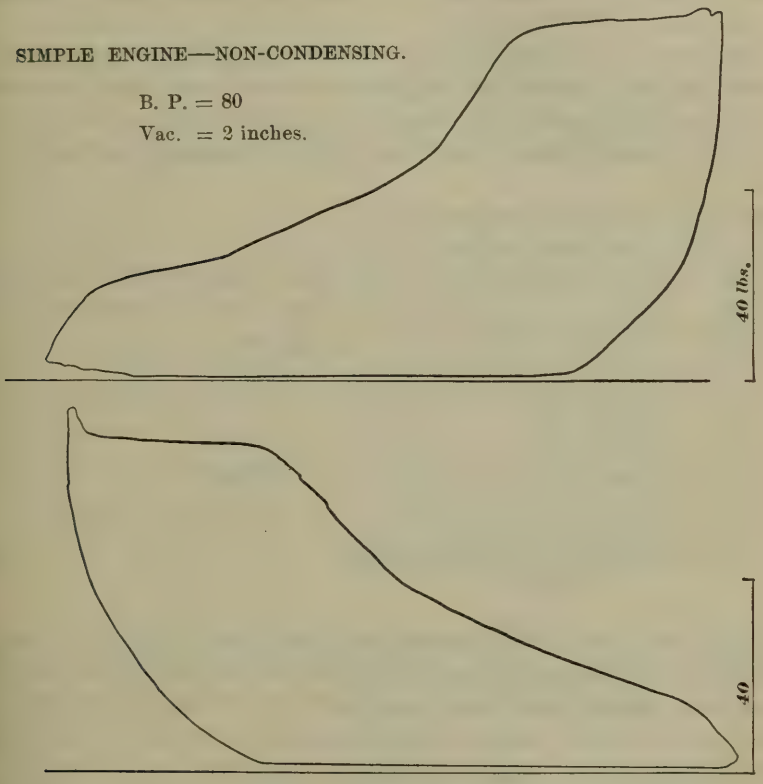


Fig. 178

Indicator diagrams and all observations were taken once in fifteen minutes on most of the tests, but on a few tests the time between observations was reduced to ten minutes.

These observations were timed by a signal, made by striking a pipe; two blows were struck twenty seconds in advance of the full time, as a preparatory signal, and one blow, two seconds in advance, as the signal for diagrams and observations. Two weigh

tanks were used, and the valves in the pipes leading to these tanks were manipulated so that the water of condensation could be weighed for each interval. The diagrams taken were at once worked out for M. E. P., by means of an Amsler's planimeter, and the indicated horse-power and the water per I. H. P. determined. It was found that these partial determinations of the water consumption ran very regularly, and seldom varied more than two or three per cent. from the mean values for the whole test.

Boiler Test.—No boiler test could be made, for the reason that the fuel was natural gas, supplied with a large head and not metered; and again, the steam was used for various other purposes and could not all be diverted to the engine to be tested.

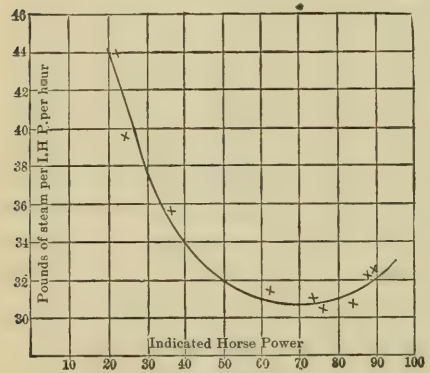


Fig. 171.

WATER CONSUMPTION PER I. H. P.—SIMPLE NON-CONDENSING ENGINE.

12 inches diam. x 14 inch stroke

245 revolutions.

Indicated Horse Power.

Rated capacity 80 H. P.

The Tests Made.—The tests made were, in addition to those relating to change of speed, as follows: *First*, with the simple engine, tests to show the water per I. H. P. and D. H. P. per hour for various loads ranging from 25 to 96 H. P., or from one-fourth to one and one-fourth its capacity; *second*, with the compound engine, non-condensing, with and without steam-jackets; *third*, condensing, with variable load and with and without steam-jackets.

Tests with the Simple Engine.—Non-condensing. Steam pressure by gauge, 80 lbs.; revolutions, 245 per minute. The results of this test are well shown on the accompanying charts, Fig. 171 and Fig. 172; from Fig. 171 it is seen that the best results were obtained with a load of 76 H. P., in which case the consumption was 30.7 lbs. of water per I. H. P. This consumption increased

as the load diminished, so that at 20 I. H. P. the steam consumption was 44 lbs. per I. H. P.; it also increased with increase of load, although at a much less rate.

The corresponding variation in the cut-off is shown in Fig. 172. The apparent cut-off, as measured from the cards, is shown by one curve, the real cut-off, in which the effect of clearance is included, by the other. It is noticed that the best results were obtained at 32.5% apparent, or 38% true, cut off.

Tests with the Compound Engine.—Two series of tests were made, one with the vacuum so as to simply overcome resistances of pipes and condensers, giving the same back pressure as when exhausting freely in the air; the other with the best vacuum attainable with the only available air-pump. The

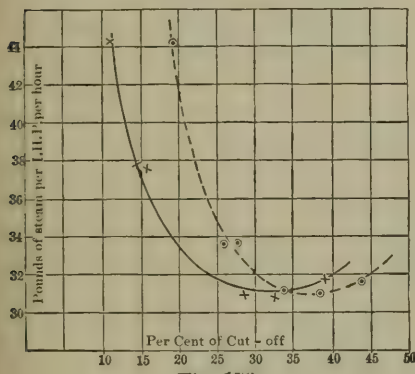


Fig. 172.

WATER CONSUMPTION FOR VARIOUS CUT-OFFS—SIMPLE NON-CONDENSING ENGINE.

J. H. McEwen Manufacturing Company.

12 x 14 Engine.

80 Pounds Steam.

245 Revolutions.

Apparent cut-off determined from indicator card. Tested July 14, 1892. R. C. Carpenter.

engine was tested in both conditions, with and without jackets in use, and between the latter limits of pressure several tests were made for steam consumption with different loads.

TESTS FOR ECONOMY WITH VARIOUS DEGREES OF EXPANSION AND VARIOUS LOADS.

In these tests the steam pressure was maintained as nearly constant as possible at 112 lbs. by gauge, and the vacuum at 22 inches, as shown by the mercury manometer attached to the condenser.

These results are shown graphically in the diagrams Fig. 173 and Fig. 174. In both diagrams, steam consumption per indicated horse-power is ordinate. In the first diagram indicated

horse-power is abscissa, in the second, total number of expansions is abscissa. Two series of tests were made, first, with both cylinders steam-jacketed; second, with neither cylinder jacketed. The results in the first series of tests are shown by the curve *A B*, and in the second series by the curve *C D*. With a better vacuum both these curves would have been somewhat lower on the sheet, showing less water consumption per indicated horse-power.

COMPOUND ENGINE WITH AND WITHOUT STEAM JACKETS.

Curve A B, steam in jackets.
Curve C D, no steam in jackets

Boiler gauge, 112 lbs.
Condenser gauge, 22 ins.
265 revolutions.
Rated capacity, 100 H. P.

Unjacketed boiler gauge, 115.3 lbs.
Condenser gauge, 23.5 ins.
Jacketed same. 265 revolutions.
Rated capacity, 100 H. P.

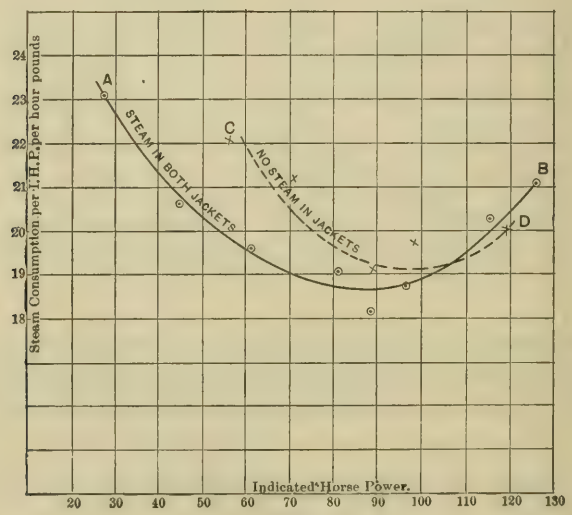


Fig. 173

As shown by the diagram, Fig. 173, the compound engine gave the best result when worked at 90 to 95 H. P., or at about its rated capacity for the limits of pressures between which it was operated. As the load varied from this the consumption of steam increased, so that at one-fourth its rated load the increase in amount of steam used was about 24%, and at one and one-

fourth its rated capacity the increase in steam consumed was about 12%.

In Fig. 174 the diagram shows the relation between water consumption per indicated horse-power and the total number of expansions in both cylinders. The best results, it is seen, were obtained in the tandem compound engine with ten expansions.

COMPOUND CONDENSING ENGINE.

J. H. McEwen Manufacturing Company.

WATER CONSUMPTION FOR VARIOUS DEGREES OF EXPANSION.

Engine 9 and 16 x 14. 265 Revolutions. 112 Steam. 22 inch Vac.
Cylinders Jacketed.

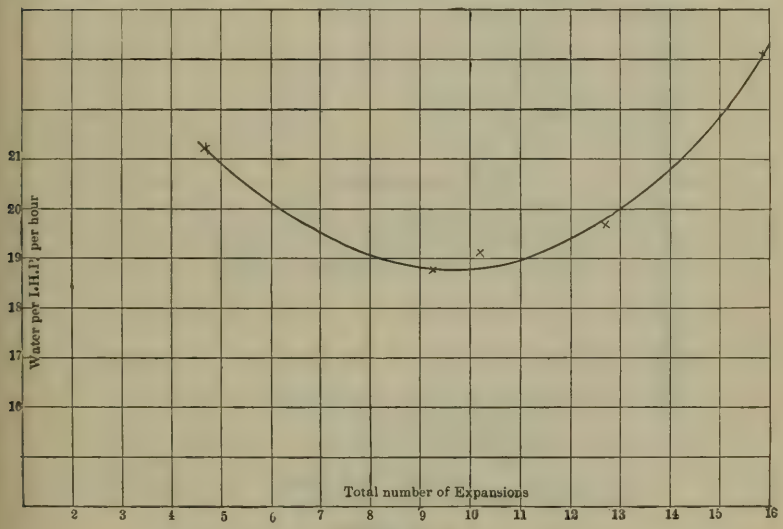


Fig. 174

COMPARISON OF PERFORMANCE OF SIMPLE AND COMPOUND ENGINE WITH VARIABLE LOADS.

A comparison of the two series of tests made on the simple and compound engine respectively is shown by the diagram in Fig. 176. The compound engine was rated at 100 H. P., was 9 and 16 inches diameter by 14-inch stroke, and working between the limits of 112 pounds of steam by gauge and 10 pounds absolute pressure. The simple engine was rated at 80 H. P., was 12 inches diameter by 14-inch stroke, and was working between the limits of 80 pounds of steam by gauge and atmospheric

pressure. The compound made 265 revolutions, the simple 245, per minute. The diagram shows the comparative results when both engines were working at rated capacity and when at less and greater capacity; the results in each case at rated capacity being considered 100. From this diagram it is seen that, for a given variation from rated capacity, the com-

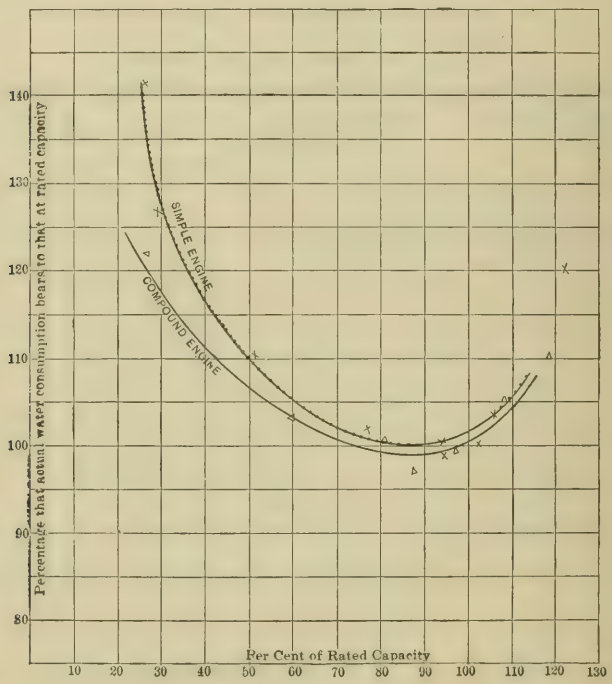


Fig. 176

pound engine is less affected than the simple. Thus, with a load 25% of that for which the engines were rated, the steam consumption with the simple engine was 143% of that at its rated capacity, the steam consumption of the compound only 124% of that at its rated capacity. In other words, the compound engine was less affected by change of load than the simple engine, under the conditions of the test. These conditions approximate very closely to those under which these classes of engines are usually worked, and indicate results directly opposed to common hypotheses respecting the performance of the two classes of engines, and confirm Mr. Rites' conclusions.

THE COMPOUND ENGINE WITH AND WITHOUT STEAM-JACKETS.

To determine the effect of using steam of boiler pressure in the jackets, two series of tests were made; one between the limits of 112 pounds boiler pressure and atmospheric back pressure, or corresponding to the condition of an engine worked non-condensing; the other between the limits of 110 pounds boiler pressure and 10 pounds absolute, it being impossible to secure less back pressure with the air-pump available for the test. Revolutions 265 in all tests.

COMPOUND ENGINE WITH AND WITHOUT STEAM JACKETS—TANDEM COMPOUND ENGINE.

J. H. McEwen Manufacturing Company.

Steam by gauge, 112 pounds.	Revolutions, 265.
Atmospheric back pressure.	Engine 9 and 16 x 14.

EXPLANATIONS.

Curve E F, no steam in jackets, average steam per I. H. P., 23.81 lbs.
Curve C D, steam in high press. jacket, average steam per I. H. P., 23.91 lbs.
Curve A B, steam in both jackets, average steam per I. H. P., 23.13 lbs.

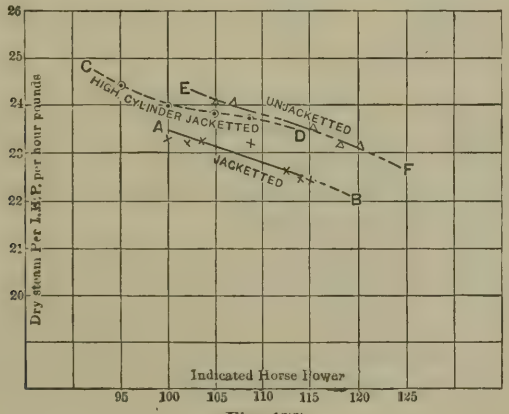


Fig. 177.

The results of the first series of tests are shown in the diagram on Fig. 177, the steam consumption per I. H. P. being ordinates, the indicated horse-power being abscissa. The line *E F* shows the results when no steam was turned in the jackets, *C D* when the high-pressure cylinder jacket only was

used, and *A B* when both cylinders were jacketed; the average results being:

No steam in jackets.....23.81 pounds per I. H. P. per hour.
Steam in high-pressure jacket.....23.91 " " " " "
Steam in both jackets.....23.13 " " " " "

In the above results and on the diagrams the weight of water condensed in the jackets is included. The jackets were furnished with steam of boiler pressure and extended around the barrel or cylindric portion of the cylinders only.

The results of the second series of tests are shown in Fig. 173. In this case the series indicated by the curve *C D* was made with no steam in the jackets; in the other case steam was used in both jackets.

The diagrams show the actual results obtained very clearly. It is seen that for most conditions the engine with the cylinders steam-jacketed consumed less than when not jacketed; that this difference was greatest for the least loads, was probably about 2% at rated capacity, and the conditions were reversed for heavy loads, the unjacketed cylinder becoming the more economical.

Considering these results only for loads between 60 and 120 H. P., we have, as the average:

With steam in jackets.....19.10 lbs. of dry steam per I. H. P. per hour.
With no steam in jackets.....20.1 " " " " " " "

These tests show in all cases a slight gain due to the use of the steam-jackets, the amounts varying in the different tests from 2.75% to 5% of the steam consumed. The use of the high-pressure jacket alone seems to have produced no especial effect, the results being better without it.

It should also be noticed, as pointed out by Dr. R. H. Thurston in Paper CCCCXXV., Vol. XII. of the *Transactions*, that in actual use the jackets would produce somewhat better results than shown in the test, due to the fact that the water of condensation from the jackets would ordinarily be returned directly to the boiler, thus saving the heat required to raise a given weight of feed water through the required range of temperature.

The following tables present in condensed form the detailed logs of the various tests:

SIMPLE AUTOMATIC ENGINE—NON-CONDENSING.

No.	Rev.	Temperatures. Air.	Eng. room.	Calo-rim'r.	Boiler Gauge not corrected.	Condenser gauge.	Electrical. Amp.	Volts.	Condensed steam.	I. H. P.	Water per I. H. P. per hour.	Remarks.
									lbs.		*lbs.*	
24..	.....	82	95	272	83	2.5	98	248	406	....	....	Load changed during this
25..	245.5	82	95	....	84	2.5	98	248	353	42.4	33.2	interval.
26..	245.5	82	...	...	83	2.5	98	248	354	41.3	34.3	
27..	.....	79	95	272	83	2.5	98	248	350	42.3	33.0	
28..	244.5	78	...	....	83	2.5	98	248	409	40.7	35.4	Interval of 17 minutes.
29..	241.5	77	90	....	83	2.5	98	248	298	40.4	31.8	" 13 "
Av.	....	....	....	....	83.16	....	....	....	....	41.4	33.6	Apparent cut-off, 19.6 p.c. Readings once in 10 m.
30..	....	76	90	...	83	2.5	42	240	....	....	....	
31..	245	73	....	....	84	2.5	42	240	149	19.7	45.3	
32 .	245	75	90	....	83	2.5	42	240	159	19.7	48.3	
33..	245	75	....	...	83	2	42	240	155	22.6	41.2	
34..	245	75	....	272	83	2	42	236	157	24.0	39.2	
35..	245	74	90	....	83	1.5	42	236	145	18.0	47.1	
36..	245	74	....	....	82.5	1.5	42	236	160	....	...	
Av.	....	....	....	....	83.01	...	....	....	....	20.8	44.1	Apparent cut-off, 11.5 p.c

Electrical horse-powers, Nos. 24 to 29 ..... 31.5
" " " 30 to 36 ..... 13.5
Corrected gauge reading, Nos. 24 to 29 ..... 80.16
" " " 30 to 36 ..... 80.01
Thermodynamical efficiency 14.1

TEST OF SIMPLE AUTOMATIC ENGINE—NON-CONDENSING.

MADE BY J. H. M'EWEN MANUFACTURING CO., RIDGWAY, PA.

Diameter cylinder, 12 inches. Length of stroke, 14 inches.

No.	Rev.	Temperatures.			Boiler gauge not corrected.	Condenser gauge.	Condensed steam.	Electrical.		I. H. P.	Water per I. H. P. per hour.	Remarks.
		Air.	Engine room.	Calorimeter.				Amperes.	Volts.			
					lbs.	*ins.*	*lbs.*					
1	245	88	94	268	81	2	.....	187	240	74	.....	The boiler gauge reads 3 pounds high, and readings in log subject to a correction of 3 pounds. Clearance of engine, 8.75%. Indicator diagrams taken with 40 spring.
2	245	86	.....	.....	80	2	598.5	195	240	77.4	30.7	
3	245	86	94	.....	79	1.5	603	195	240	76.3	31.7	
4	245	87	.....	269	80	1.5	601	195	240	75.4	31.9	
5	245	88	93	.....	82	2	595	195	240	75.9	31.4	
6	245	89	.....	270	81	2	586	195	240	75.4	31.0	
7	245	90	.....	272	80	2	576	195	240	74.0	31.1	
8	245	90	.....	.....	81	1.5	569	195	240	73.6	31.0	
9	245	88	95	270	80	2	595.5	195	240	76.7	31.0	
10	245	88	.....	.....	80	2	597	195	240	75.9	31.4	
11	245	89	.....	273	80	1.5	559	195	240	74.7	30.9	
12	245	86	.....	.....	80	2	617	195	240	75.0	31.8	
13	244.5	85	97	273	80	2	565	195	240	75.4	30.0	
14	244.5	85	97	.....	81	2	601	195	240	76.2	31.7	
15	244.5	84	95	273	80	2	591	195	240	76.2	31.1	
16	244.5	83	95	.....	81	2	581	195	240	76.2	30.6	
17	244.5	83	95	273	80	2	589	195	240	75.9	30.9	
18	244.5	83	.....	.....	80	2	590	195	240	76.7	30.75	
19	245	83	.....	.....	81	2	591	195	240	76.3	30.5	
20	245	83	95	273	81	2	578	195	240	76.4	30.2	
21	245	83	.....	.....	80	2	594	195	240	77.0	30.8	
22	245	83	.....	273	80	2	603	195	240	77.0	31.15	
23	245	83	94	.....	80	2	606	195	240	76.5	31.8	

AVERAGES.

Quality of steam	99.5 per cent.
Indicated horse-power	75.85
Electrical horse-power	62.7
Water per I. H. P. per hour	31.1
Dry steam per I. H. P. per hour	30.95
Apparent cut-off	31.5
True cut-off	37.5
Corrected boiler pressure	77.35
Thermodynamical efficiency	13.7 per cent.

From Diagram.

Admission pressure, absolute	90.5
Release " "	33.5
Back " "	15.5

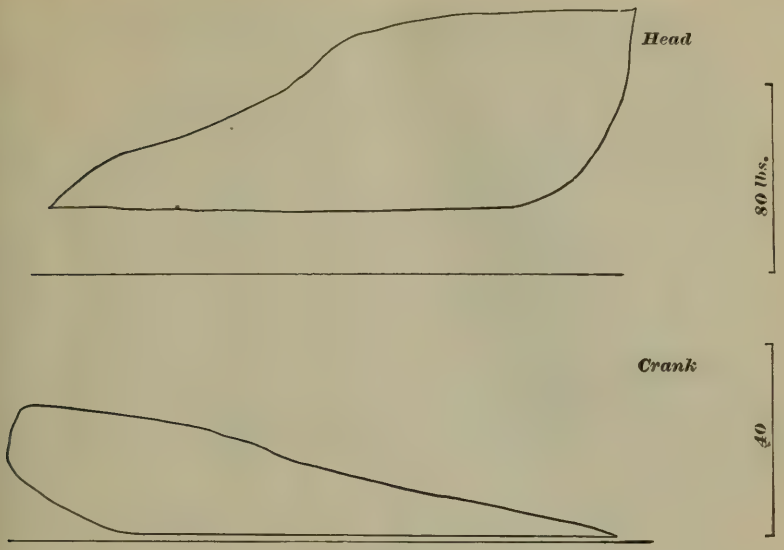


Fig. 179

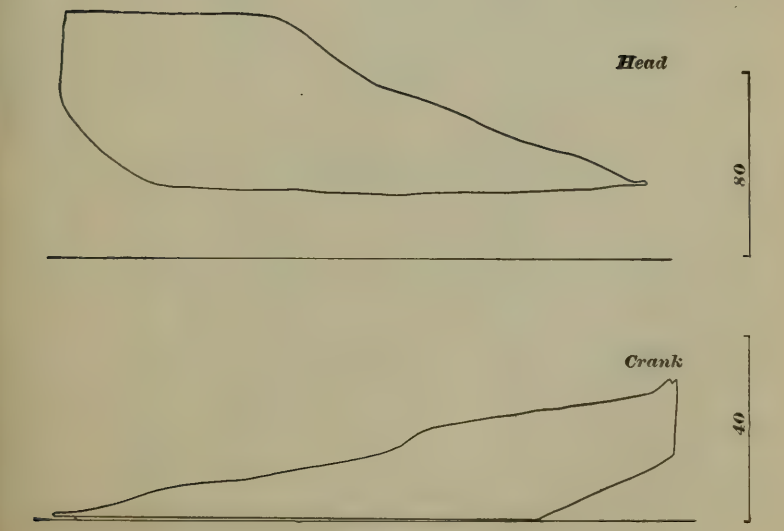


Fig. 180

TANDEM COMPOUND ENGINE.

J. H. McEwen Manufacturing Co. 9 and 16 by 14. Steam in high-pressure jacket only. Log of test of July 22, 1892. Non-condensing.

Time.	No.	Temperature. Air.	Temperature. Engine Room.	Temperature. Calorimeter.	Weights. Gross. North Barrel.	Weights. Gross. South Barrel.	Weights. Net. North Barrel.	Weights. Net. South Barrel.	Total.	Temperature, F.	Revolutions.	Brake Load.	Electrical. Amperes.	Electrical. Volts.	H.P.	Brake H.P.	Total D.H.P.	Boiler Gauge.	Cond. Gauge.	Jacket Water.	Temp. Jacket Water.	Indicator Diagrams. High Pressure. M.E.P. Hd	M.E.P. Cr.	I.H.P. Hd.	I.H.P. Cr.	Low Pressure. M.E.P. Hd.	M.E.P. Cr.	I.H.P. Hd.	I.H.P. Cr.	I.H.P. High-Pressure Cyl.	I.H.P. Low-Pressure Cyl.	Total I.H.P. Engine.	Water per I.H.P.
					(a)	(b)				°		+						*	In.														
1.10	0	..	....								267	57	147	240				111	2			20	45 4	14.1	26.2	8.6	8.3	16.5	15.0	40.3	31.05	....	....
1.20										103 N.												46.6	49.6	22.5	28.6	14.2	15.2	26.6	27.8	51.1	54.4	105.5	22.2
1.25	1 98	94	274		242	415	179	369	583	103 S.	265	150	170	240				110	2			45.0	46.2	26.5	26.3	13.7	14.4	24.6	26.5	55.8	51.1	106.9	22.0
1.40	2 90	....	....		330	425	267	369	636	102 / 101	265	150	170	240				110	3			42.2	46.0	25.0	26.2	13.3	13.7	24.7	24.7	51.5	49.4	100.9	25.1
1.55	3 90	94	....		270	430	207	404	611	107 / 106	265	150	170	240				109	2			48.2	48.4	28.6	27.5	14.2	12.8	26.5	23.5	56.1	50.0	106.0	23.0
2.10	4 89	92	....		265	483	202	427	609	110 / 109	265	150	170	240				110	2	....		43.0	48.0	25.5	27.2	12.0	13.4	22.4	24.5	52.7	46.9	99.3	24.2
2.25	5 92	95	278		261.5	465	198.5	409	607.5	108 / 109	265	150	170	240				112	2	1.35 P.M. 18 lbs.	172	45.4	48.2	26.8	27.4	13.4	14.1	25.0	25.7	54.2	50.7	104.9	23.7
2.40	6 90	95	280		264	493	201	437	638	107 / 108	265	150	170	236	Average, 54.5.	Average, 33.4.	Average, 87.9.	105	2	.... ..	....	46.0	48.0	27.3	27.2	13.7	14.7	25.5	27.0	54.5	52.5	107.0	23.8
2.55	7 86	92	280		268	465	205	409	614	104 N. / 106 S.	265	150	170	236				110	2.5	.....	. ..	44.2	48.0	26.2	27.2	12.5	13.8	23.3	25.3	53.4	48.6	102.0	24.1
3.10	8 92	94	..		242.5	485	179.5	420	608	103 / 105	265	150	170	236				112	3	18	167	41.2	51.0	24.3	29.9	13.1	13.6	24.2	24.9	54.2	49.1	103.3	23.5
3.25	9 92	....	..		262	481	190	429	621	105 / 102	265	150	172	240				110	2	.....	....	43.2	51.6	25.5	30.3	13.2	13.1	24.7	22.8	55.8	47.5	103.5	23.8
3.35	10 89	....	....		0	450	....	394	394	107	265	150	160	232				115	2	18	....	38.4	50.4	22.7	29.6	11.5	12.2	21.5	22.2	52.3	43.7	96.0	24.6
3.46	11 88	96	....		494	0	431	...	431	106	265	140	160	232				115	2	.....	...	42.0	49.4	24.8	29.0	11.9	12.8	22.2	23.4	53.8	45.6	99.4	23.6
4.00	12 86	94	281		199	477	136	421	557	107 / 106	265	140	173	232				115	2	17.5	....	43 8	49.4	26.5	28.5	12.2	13.0	22.8	23.7	55.0	46.5	101.5	23.8
4.16	13 87	94	282		278	468	215	412	627	111 / 110	265	140	170	232				115	2	19.5	...	42	50.4	24.9	29.1	12.1	13.2	22.6	24.2	54.0	46.8	100.8	23.2
4.30	14 84	....	282		195	475	132	418	550	112 / 112	265	160	170	236				115	2	18.5	170	44	51.6	26.1	29.8	11.6	12.3	21.6	22.6	55.9	44.2	100.1	23.5
4.45	15 83	94	282		232	468	168	411	579	112 / 114	262.5	160	170	236				115	2	13.0	....	43	51.4	25.5	29.6	12.0	12.8	22.4	23.5	55.1	45.9	101.0	22.9
5.00	16 83	..	...		232	476	168	419	587	111 / 112	263	160	170	236				...	...	.....	....	40.6	50.6	24.1	29.2	11.2	12.3	20.9	22.6	53.3	43.5	96.8	24.2

Quality of steam = .998.

Compound non-condensing.
9″ + 16″ × 14″.

Average H.P. = 102.1.
Average steam consumption = 23.58 lbs. per I.H.P. per hour.
Add jacket water = 0.33 " " " " "
Total = 23.91 " " " " "

* These readings are 3 lbs. high.

† Subject to correction of 25 lbs. tare.

(a) Deduct 63 lbs. for tare. (b) Deduct 56 lbs. for tare.

TANDEM COMPOUND ENGINE.

9 and 16 by 14. Steam in both Jackets. Log of Test. Non-Condensing.

Time.	No.	Temperature. Air.	Temperature. Engine Room.	Temperature. Calorimeter.	Weights. Gross. N. Barrel.	Weights. Gross. S. Barrel.	Weights. Tare. N. Barrel.	Weights. Tare. S. Barrel.	Weights. Net. N. Barrel.	Weights. Net. S. Barrel.	Weights. Total.	Temperature, F. °	Revolutions.	Brake Load. +	Electrical. Amperes.	Electrical. Volts.	H.P.	Brake H.P.	Total D.H.P.	Boiler Gauge. *	Cond. Gauge. In.	Jacket Water.	Temp. Jacket Water.	Indicator Diagrams. High Pressure. M.E.P. Hd.	M.E.P. Cr.	I.H.P. Hd.	I.H.P. Cr.	Low Pressure. M.E.P. Hd.	M.E.P. Cr.	I.H.P. Hd.	I.H.P. Cr.	I.H.P. High-Pressure Cyl.	I.H.P. Low-Pressure Cyl.	Total I.H.P. Engine.	Water per I.H.P.	Without Jacket Water.
5.15	17	84	92	282	210	481	64	57	146	424	560	109 N. / 110 S.	264	160	178	236				115	2	18.5 / 20.5	170	38.6	45.6	22.7	26.6	13.0	14.2	24.2	26.0	49.3	50.2	99.5	22.5	
5.30	18	83	....	....	218	475	64	57	154	418	572	109 / 110	265	160	174	236				115	2	21.5 / 14.0	.....	39	47.8	23.0	28.0	12.8	15.0	23.9	27.5	51.0	51.4	102.4	22.5	
5.45	19	83	88	278	222	472	64	57	158	415	573	109 / 110	265	160	170	236				115	2	12.5 / 17.0	174	39	46.2	23.0	27.1	13.3	14.6	24.8	26.7	50.1	51.5	101.5	22.6	
6.00	20	82	....	....	231	479	64	57	167	422	589	109 / 109	265	160	170	236				115	2	17.5	170	46	48.6	27.2	28.2	12.6	15.00	23.5	27.4	55.4	50.9	106.3	22.3	
6.15	21	74	....	280	222	480	64	57	158	423	581	107 / 109	265	160	170	236				116	2	15.5 / 15.0	.....	41	46.4	24.2	27.3	15.5	13.2	28.9	24.2	51.3	53.1	104.4	22.6	
6.30	22	74	86	....	235	477	64	57	171	420	541	105 N. / 106 S.	265	170	170	236				115	2	21.5 / 16.5	173	42	47.2	24.7	27.3	16.0	13.5	29.8	24.7	52.0	54.5	106.5	22.4	
6.45	23	72	....	....	320	432	64	57	256	375	631	105 / 105	265	170	165	236				115	2	18	... ...	43	48.4	24.8	27.9	16.7	14.0	31.1	25.6	52.7	56.7	109.4	23.2	
7.00	24	72	80	280	204	457	64	57	140	400	540	102 / 102	264	170	165	236				115	2	11¾ / 18	175	46	41	27.2	24.7	13.5	15.5	25.7	28.4	51.9	54.1	105.0	20.7	
7.15	25	74	....	....	267	445	64	57	203	388	591	104 / 104	264	170	165	236				115	2	19	.. ...	40	47.2	23.6	27.3	13.5	13.0	25.7	27.4	50.9	53.1	104	22.7	
7.30	26	72	....	....	222	469	64	57	158	412	570	104 / 104	264	170	165	236				115	2	17.5	. . ...	41	47.2	24.2	27.3	12.5	14.4	23.3	26.4	51.5	49.7	101.2	22.5	
7.45	27	70	81	230	246	485	64	57	182	428	610	103 / 104	264	170	165	236				115	2	20¼	172 / 171	42.6	47.2	25.2	27.3	14.1	14.1	26.3	25.8	52.5	52.1	104.6	23.4	
8 00	28	68	82	....	234	470	64	57	200	413	613	104 / 103	264	170	172	230				115	2	18	171	44.4	47	26.3	27.1	14.9	17.5	27.7	32.0	53.4	59.7	113.1	21.8	
•																																				Average I.H.P., 107.645.

* These readings are 3 lbs. high.

† Subject to correction of 3 lbs. tare.

TANDEM COMPOUND ENGINE.—*Continued.*

9 and 16 by 14. Steam in both Jackets. Log of Test. Non-Condensing.

Time.	No.	Temperature. Air.	Temperature. Engine Room.	Temperature. Calorimeter.	Weights. Gross. N. Barrel.	Gross. S. Barrel.	Tare. N. Barrel.	Tare. S. Barrel.	Net. N. Barrel.	Net. S. Barrel.	Total.	Temperature F. °	Revolutions.	Brake Load. †	Electrical. Amperes.	Volts.	H.P.	Indicator Diagrams.	Boiler Gauge. *	Cond. Gauge.	Jacket Water.	Temp. Jacket Water.	High Pressure. M.E.P. Hd.	High Pressure. M.E.P. Cr.	High Pressure. I.H.P. Hd	High Pressure. I.H.P. Cr.	Low Pressure. M.E.P. Hd.	Low Pressure. M.E.P. Cr.	Low Pressure. I.H.P. Hd.	Low Pressure. I.H.P. Cr.	I.H.P. High-Pressure Cyl.	I.H.P. Low-Pressure Cyl.	Total I.H.P. Engine.	Water per I.H.P.	Without Jacket Water.
8.15	29	68	82	....	278	461	64	57	214	404	618	106 / 104	263	170	170	232			115	2	18	....	44.4	49.6	26.3	28.6	14.9	16.3	27.7	29.8	54.9	58.5	113.4	22.5	
8.30	30	67	....	280	305	435	64	57	241	378	619	108 / 108	265	170	170	232			115	2	21 / 18	174	43.4	47.6	25.6	27.4	14.3	15.5	26.7	28.4	54.0	51.1	105.1	23.7	
8.45	31	67	82	....	235	496	64	57	171	439	610	110 / 110	265	170	170	232			115	2	20	.....	42	48.8	24.7	27.7	14.7	16.3	27.4	29.9	52.4	57.3	109.7	22.4	
9.00	32	66	80	...	273	457	64	57	209	400	609	111 / 112	263	170	170	232			115	2	17.5	170	43.2	48	25.6	27.2	16.2	17	30.2	31.2	52.8	61.4	112.2	21.6	
9.15	33	66	....	....	234	510	64	57	170	453	623	112 / 112	264	170	170	232			115	2	18	.....	43.6	49	25.9	28.2	15.0	16.2	27.9	29.8	54.1	57.7	111.8	22.4	
9.30	34	66	....	....	267	467	64	57	203	410	613	112 / 113	263	170	170	232			115	2	18	175	43.6	50.8	25.9	29.4	14.4	16.2	26.8	29.8	55.3	56.6	111.9	21.9	
9.45	35	69	76	....	267	465	64	57	203	408	611	113 / 112	264	170	170	232			115	2	20 / 17	174	51.0	45	30.3	26.0	15.0	16.2	27.9	29.8	56.3	57.7	114.0	21.5	
10.00	36	65	....	....	266	472	64	57	202	415	617	112 / 111	265	170	170	232			115	2	20 / 20	170	52.8	43.6	31.3	25.2	15.7	17.0	29.2	31.2	56.5	60.4	116.9	21.2	

Average, 52.4. Average, 38.1 H.P. Average, 90.5.

Average I.H.P., 107.645.

July 22, 1892.

Both jackets in use.

Jacket Water, Total, 438 lbs.
87.6 per hr. = 0.815 per I.H.P. per hr.

Water per I. H. P. per hour.
22.32
.815
23.135

* These readings are 3 lbs. high.

† Subject to correction of 3 lbs. tare.

TANDEM COMPOUND ENGINE.

9 and 16 by 14. No Steam in Jackets. Log of Test. Not Condensing.

Time.	No.	Temperature. Air.	Temperature. Eng. Room.	Temperature. Calorimeter.	Weights. Gross. N. Barrel.	Weights. Gross. S. Barrel.	Weights. Tare. N. Barrel.	Weights. Tare. S. Barrel.	Weights. Net. N. Barrel.	Weights. Net. S. Barrel.	Weights. Total.	Temperature, F.	Revolutions.	Brake load.	Electrical. Amperes.	Electrical. Volts.	Electrical. H. P.	Brake H. P.	Total D. H. P.	Boiler gauge.	Condenser gauge.	Indicator Diagrams. High Pressure. M. E. P. Hd.	M. E. P. Cr.	I. H. P. Hd.	I. H. P. Cr.	Indicator Diagrams. Low Pressure. M. E. P. Hd.	M. E. P. Cr.	I. H. P. Hd.	I. H. P. Cr.	I. H. P. High-pressure.	I. H. P. Low-pressure.	Total I. H. P. Engine.	Water per I. H. P.
												°		+						*	In.												
11.20	0	..	87	....	....	....	..	..	...	...	....	.....	265.5	170	115	238				111	2	45.2	51.4	26.7	29.7	13	14.6	24.1	26.8	56.4	50.9	107.3	....
11.30	1	86	88	....	....	499	64	56	....	446	446	116	265	170	162	242				108	2	49	49.6	28.8	28.8	14.6	16.6	27.1	30.4	57.6	57.5	115.1	23.2
11.45	2	86	88	280	477	343	64	56	413	287	700	121 / 123	264.5	170	165	240				110	2	48	50.6	28.4	29.4	13.7	16.4	25.5	30.1	57.8	55.6	113.4	24.6
12.00	3	87	88	280	493	280	64	56	429	224	653	120 / 120	263	170	172	235				112	2	45.6	50.0	27.0	26.4	13.5	15.0	25.2	27.5	53.4	52.7	106.1	24.6
12.15	4	88	88	..	428	367	64	56	364	311	675	122 / 123	263.5	170	177	232				112	2	47	50.8	28.2	29.2	15.0	16.3	27.9	29.9	57.4	57.8	115.2	23.5
12.30	5	88	86	...	460	351	64	56	396	285	681	122 / 124	264.5	170	180	235				112	2	52.2	49.8	31	28.8	14.9	17.8	27.8	32.6	59.8	60.4	120.2	22.5
12.45	6	88	85	....	436	339	64	56	372	283	655	123 / 123	267	170	165	232				112	2	47.4	48.6	28.1	28.7	13.8	16.7	25.6	30.6	56.8	56.2	113.0	23.5
1.00	7	90	..	276	477	305	64	56	413	249	662	124 / 125	266	170	174	234				112	2	50.0	50.6	29.6	29.2	17.5	15.5	32.5	28.4	58.8	60.9	119.7	22.2
1.15	8	91	..	....	476	326	64	56	412	270	682	125 / 125	266	170	170	234				112	2	49.8	50.2	29.5	29.0	15.2	15.9	29.4	29.1	58.5	58.5	117	23.4
1.30	9	90	90	276	461	362	64	56	397	307	704	126 / 126	267	170	174	234				112	2	48.0*	50.8	28.4	29.3	14.5	16.3	27.0	29.8	57.7	57.8	115.5	24.5
1.45	10	91	..	....	458	358	64	56	394	302	696	125 / 126	267	170	170	232				112	2	48.6	52	28.7	30.0	14.1	16.8	26.3	30.7	58.7	57.0	115.7	24.1
2.00	11	92	95	....	472	333	64	56	408	277	685	127 / 127	267	170	171	228				112	2	48.4	51	28.7	29.4	14.8	16.4	27.6	30.0	58.1	57.6	115.7	23.7
2.15	12	92	95	....	459	371	64	56	395	315	710	128 / 129	267	170	170	238				111 2	2	47.6	50	28.1	28.8	15.0	16.8	27.9	30.7	56.9	58.6	115.5	24.6

Average electrical H. P. = 52.6.

Average, 88.3.

Average, 90.9.

* Readings corrected.

† Subject to correction of 25 lbs. tare.

TANDEM COMPOUND ENGINE.—*Continued.*

9 and 16 by 14. No Steam in Jackets. Log of Test. Not Condensing.

Time.	No.	Temperature. Air.	Temperature. Eng. Room.	Temperature. Calorimeter.	Weights. Gross. N. Barrel.	Weights. Gross. S. Barrel.	Weights. Tare. N. Barrel.	Weights. Tare. S. Barrel.	Weights. Net. N. Barrel.	Weights. Net. S. Barrel.	Total.	Temperature, F.	Revolutions.	Brake load.	Electrical. Amperes.	Electrical. Volts.	H. P.	Brake H. P.	Total D. H. P.	Boiler gauge.	Condenser gauge.	Indicator Diagrams. High Pressure. M. E. P. Hd.	High Pressure. M. E. P. Cr.	High Pressure. I. H. P. Hd.	High Pressure. I. H. P. Cr.	Low Pressure. M. E. P. Hd.	Low Pressure. M. E. P. Cr.	Low Pressure. I. H. P. Hd.	Low Pressure. I. H. P. Cr.	I. H. P. High-pressure.	I. H. P. Low-pressure.	Total I. H. P. Engine.	Water per I. H. P.
												°		+						*													
2.30	13	91	95	278	455	371	64	56	391	315	706	126 / 118	266	170	171	236				112	2	48.0	50.4	28.4	29.1	15.5	17.9	28.9	32.8	57.5	61.7	119.2	22.7
2.45	14	93	..	....	476	358	64	56	412	302	714	113 / 118	266	170	175	238				112	2	49	51.0	29	29.4	15.5	16.5	28.9	30.0	58.4	58.9	117.3	24.4
3.00	15	92	92	278	457	385	64	56	393	329	722	118 / 119	266	170	170	236				111	2.5	51.4	50.6	30.4	29.3	15.6	17.5	29.1	31.8	59.7	60.9	120.6	23.8
3.15	16	94	92	278	453	411	64	56	389	355	744	120 / 121	266	170	173	236				112	2	50	51.0	29.6	29.4	16.1	17.4	30.0	31.7	59.0	61.7	120.7	24.5
3.30	17	93	..	....	468	357	64	56	404	301	705	120 / 119	267	170	175	232				111	2	48.6	49.2	28.8	28.5	14.6	16.3	27.2	29.9	57.3	57.1	114.4	24.7
3.45	18	89	92	....	457	372	64	56	393	316	709	119 / 120	266	170	174	232				112	2	50	50.4	29.7	29.2	15.2	17.1	28.1	31.4	58.9	59 5	118.4	24.0
4.00	19	90	93	280	467	346	64	56	403	290	693	119 / 119	267	170	172	232				113	2	48	52.4	28.5	30.2	14.0	15.2	26.1	27.9	58.7	54.0	112.7	24.2
4.15	20	90	92	280	466	307	64	56	402	251	653	117 / 117	266	170	167	230				114	2.5	46.4	53.4	27.5	30.9	12.2	14.0	22.7	25.7	58.4	48.4	106.8	24.5
4.30	21	88	..	....	449	309	64	56	385	253	638	118 / 118	266	170	165	230				112	2	46.8	50	27.7	28.9	12.4	14.3	24	26.2	56.6	50.2	106.8	23.8
4.45	22	89	92	....	444	316	64	56	380	260	640	118 / 118	266	170	163	229				112	2	46	48.8	27.3	28.3	12.5	14.3	23.3	26.2	55.6	49.5	105.1	24.1
5.00	23	88	92	280	452	310	64	56	388	254	642	118 / 117	266	170	163	229				112	2	45.8	50.4	27.2	29.5	13.3	14.2	24.8	26.0	56.7	50.8	107.3	24.0
																	Average electrical H. P. = 52.6. Average, 38.3. Average, 90.9.																	
																																Average =	113.5	23.81

July 23, 1892. No jackets used. Compound non-condensing 9″ + 16″ × 24″.

* Readings corrected. † Subject to correction of 25 lbs. tare.

ADDED AT THE MEETING.

The diagrams shown on page 431 (Fig. 178), should be accompanied with an explanation. The lower figure was taken from the simple engine when exhausting freely into the air; the upper one from the same engine exhausting into the condenser when the vacuum gauge read 2 inches. The proof of the diagrams could not be seen, and the omission of the explanation was not noted until the paper was published.

The report of the tandem compound engine non condensing with and without jackets was omitted by mistake from the copy presented at the meeting, it is added here by request.

Barometer 28.6	14.1
Release pressure	33.5
Term'l pressure	31.1
M. E. P.	39.0
Spring	40
Water per H. P.	24.6

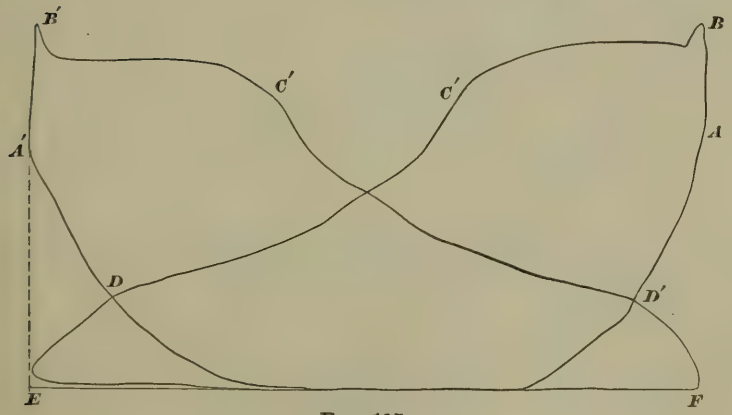


FIG. 195.

TANDEM COMPOUND ENGINE WITHOUT JACKETS.

No.	Rev.	Boiler gauge.	Condenser gauge.	Condensed steam, lbs.	I.H.P.	Water per I.H.P. per hour.	Quality of steam.	Absolute back pressure on diagram, lbs.	Lbs.	Date.
0	265	115	24.	.....	101.8	.....	.....	.....	.....	August 4, 1892.
1	265	112	25.2	316	95.2	19.4	.....	.....	.....	
2	265	115	25.	331	99.9	19.8	.....	.....	.....	
3	265	112	25.5	325	95.8	20.2	.....	.....	.....	
4	265	112	28.	324	99.8	19.4	.....	.....	.....	
5	265	112	26.	315	96.6	19.6	.....	.....	.....	
6	265	115	25.5	311	92.8	20.0	.....	.....	.....	
7	265	115	25.5	327	101.7	19.4	.....	.....	.....	
8	265	115	25.5	335	97.9	20.5	.....	.....	.....	
9	265	115	25.5	328	98.71	19.9	.....	.....	.....	
		114	25.1		97.82	19.8	99	2		
10	263	115	25.5	279	72.4	.....	.....	.....	.....	
11	263	115	25.5	263	73.1	21.6	.....	.....	.....	
12	263	115	25.	287	69.0	21.4	.....	.....	.....	
13	263	115	25.	241	69.2	1.0	.....	.....	.....	
14	263	115	25.	243	68.1	21.4	.....	.....	.....	
	263	115	25.1		70.3	21.3	99	2		

TANDEM COMPOUND ENGINE WITH JACKET.

7	264	115	25.	.....	100.4	17.5	17	.....	.....	August 2, 1892.
8	264	115	23.5	294	91.7	18.15	16	.....	.....	
9	264	115	24.	280	95.4	16.9	15	.....	.....	
10	264	115	23.5	269	93.1	.....	18	.....	.....	
11	264	115	23.5	277	89.2	17.7	17	.....	.....	
12	264	115	23.25	272	96.5	18.3	17	.....	.....	
13	264	115	23.	309	92.3	18.3	18	.....	.....	
14	264	115	24.	253	95.2	17.4	16	.....	.....	
15	264	115	.....	290	102.4	.....	19	99	.....	
16	264	115	.....	296	95.1	17.8 1.3 J. W.*	17 or 1.32 per I.H.P.		5	
Av...		115	23.8	.....	.....	19.1				
17 to 22										
Av...	264	112	24.	243	80.5	17.85 1.03 J.W.* 18.90	1.03 per I.H.P. 18.7 or	99	3	
23	264	115	24.	209	60.8	20.5	17.	.....	.....	
24	264	115	24.	198	59.7	18.2	18.5	.....	.....	
25	264	115	23.5	163	60.07	16.9	16.	.....	.....	
26	264	115	24.	190	61.2	18.5	15.	.....	.....	
27	264	113	23.5	176	60.9	17.3	17.	.....	.....	
28	264	113	23.	189	62.1	18.3	17.5	.....	.....	
29	264	120	22.5	172	59.8	17.3	14.	.....	.....	
30	264	115	22.5	175	61.6	17.05	17.	.....	3	
Av...		114.5	.....	.....	61.03	18.0 1.69 J.W.*	16.5	99		
						19.69				
31	264	115	23.	90	25.16	21.5	16.	.....	.....	
32	264	115	24.	76	29.34	15.5	.....	.....	.....	
33	264	115	19.5	111	27.02	24.7	16.	.....	3	
					27.17	20.56 2.55 J.W.*		99		
						23.11				

* Jacket water per I.H.P. per hour.

TEST OF TANDEM COMPOUND ENGINE. 9 AND 16 BY 14. CONDENSING. STEAM JACKETS NOT USED.

Abstract of Log.

No.	Rev.	Boiler gauge.	Condenser gauge, inches.	Condensed steam, lbs.	I.H.P.	Water per I.H.P. per hour.	Calorinde temperature.	Per cent. of moisture.	Absolute back pressure from diagram.	Date.
0	265	112	23.5	.....	92.5	17.4	.....	.....	.....	August 3, 1892.
1	264	109	24.5	267	84.4	18.2	.....	.....	.....	
2	264	109	24.	276	86.2	19.1	274	.....	.....	
3	264	112	24.	281	87.6	19.4	.....	.....	3	
4	264	109	24.	285	88.7	19.3	.....	.....	.....	
5	264	109	24.	291	88.8	19.8	.....	.....	3	
6	264	107	24.	286	87.7	19.4	272	.....	.....	
7	264	107	25.	302	88.9	20.4	.....	.....	3	
8	264	107	24.	310	90.6	20.5	.....	.....	.....	
Av...	264	109	24.12	.....	88.8	19.2	273	1.0	3.5	
9	264	102	23.5	392	130.9	17.9	.....	.....	3.5	
10	264	97	23.5	402	127.7	19.0	.....	.....	.....	
11	263	77	23.2	424	110.8	23.0	.....	.....	.....	
12	266	87	23.	433	117.8	22.2	267	.....	3.5	
13	266	100	23.2	436	119.9	21.7	.....	.....	.....	
14	266	112	23.5	404	114.4	21.2	.....	.....	.....	
15	266	112	23.5	480	115.7	20.75	.....	.....	3.5	
16	265	112	23.5	312	117.3	20.0	.....	.....	.....	
17	264	112	23.5	396	119.0	19.9	.....	.....	.....	
Av...	264.9	104.9	23.4	.....	119.3	20.1	267	.....	3.5	

TANDEM COMPOUND ENGINE.

J. H. McEwen Manufacturing Company. 9 and 16 by 14.

No.	Rev.	Boiler gauge.	Condenser gauge, inches.	Condensed steam, lbs.	I.H.P., total.	Steam per I.H.P.	Jacket water.	Barometer 28.2. Absolute back pressure from diagram.	Barometer 28.2. Quality of steam.	Date.
9	264	107	19.	430	127.1	20.4	.....	.....	.....	July 27, 1892.
10	264	104	19½	447	125.6	21.3	15	.....	.....	
11	264	104	19½	444	125.2	21.3	9	.....	.....	
Av...					126.0	20.9 .3 J. W.*	6	5.2	98.9	
11	264	110	22.5	.....	.....	.....	.....	.....	.....	
12	264	110	22.5	397	117.9	20.1	14	.....	.....	
13	264	112	22.5	581	116.4	20.0	16	.....	.....	
14	264	112	22.5	592	114.1	20.7	15	.....	.....	
15	264	112	22.5	560	125.4	18.0	.....	.....	.....	
Av...					118.4	19.7 .65 J. W.	72 per hour.	98	4.5	
						20.3				

ABSTRACT OF RESULTS OF TEST.

COMPOUND CONDENSING WITHOUT JACKET.

Rev.	Boiler gauge.	Condenser gauge.	I.H.P.	Steam per I.H.P.	Absolute back pressure.
263	115	25.1	70.3	21.3	3
264	109	24.1	88.8	19.2	.....
265	111	25.1	97.82	19.8	.....
265	105	23.4	119.3	20.1	.....
		COMPOUND CONDENSING WITH JACKET.			
264	115.	22.	27.17	23.11	3.
264	114.5	23.	61.63	19.69	3.
264	115.	23.8	95.1	19.1	5.
264	112.	22.5	118.4	20.3	4.5
264	104.	19¼.	126.	21.2	5.2

DISCUSSION.

Prof. R. H. Thurston.—Professor Carpenter has given us an interesting series of results of test of a new and, in some respects, novel and very interesting form of high-speed engine. Its indicator diagram is an exceptionally good one for that type of valve-gear and method of steam distribution; and the economical performance of the machine may be rated, I think, as high for a single valve. In the comparisons, the higher speed of the compound gives it a slight advantage; but, I presume, not to exceed one, or at most, two per cent. The rating of the simple engine is remarkably close to its best performance, a little above rather than below 0.7 H.P. per square inch of piston area. The curve shows its best rating, economically, to be close to 70 H.P., or a trifle over 0.6 H.P. per square inch, under the conditions of the test. The variation of steam consumption seems unusually symmetrical on either side of the minimum, within a wide range. An interesting fact is the close coincidence between the cut-off of minimum steam consumption and that observed by Engineer-in-Chief Isherwood in the naval engines reported upon by him in his *Researches in Steam Engineering* thirty years ago. He found 0.4 to be best, in this respect, for the comparatively large unjacketed simple engines of his time, the real cut-off being considered.

The compound engine, like the simple, has a rating somewhat above its most economical power, but I should think wisely. In a large proportion of cases the engine is called upon to work

at a mean power less than its rated capacity, rather than above. Here the rating is 0.5 the piston-area; the highest economy of steam is found at 0.45, as tested. The loss of efficiency is substantially uniform on either side the minimum for a considerable range of power.

The gain of one-third, as compared with the simple engine, I should attribute mainly to the condenser, in a less degree to the increased pressure and higher expansion, and in minor extent to the somewhat higher speed of rotation. The later tests show the condenser to have saved about four pounds out of the ten or eleven, which is less than would probably be expected where a condenser is attached to a simple engine. Condensation and higher speed, together raise the maximum expansion in a single cylinder from 2.5 in the simple to above 3 in the compound. The designer has struck precisely the right proportions, apparently. The steam consumption, at highest economy, is that which seems to be about the usual and best figure for compound engines of the better class under similar circumstances. Between 18 and 19 lbs. of steam per hour and per horse-power is coming to be a very familiar figure with the machines of this class by the best makers, worked condensing, as 22 or 23 may be taken as representative of best work for the non-condensing engine.

The curves shown in Fig. 176 are the best illustration that I have met with of the methods of variation of water and steam consumption with varying power for the two classes of engine. Mr. Rites and the builders of the Westinghouse engine have prepared us to concede the possibility of the compound engine proving superior to the simple, with wide variation of load, when properly designed for such variable conditions, even when non-condensing; but I presume that all compound engines reach a limit in this respect, when the expansion line begins to fall below the back-pressure line with increasing expansion; and are at a disadvantage, as compared with the simple, in this respect, when approaching that limit, in consequence of their greater internal resistance. The peculiar steam distribution of the Westinghouse engine gives it some immunity from this limiting action, and sets it in a class by itself.

The experiments with the jackets are exceptionally interesting, though the fact that the jackets were applied only to the barrel, where it is well understood that they can have comparatively little effect in any case, and not to the heads, where they

would have maximum value, reduces their influence to a minimum. As is usual in such engines, we find the jacket useless on the high-pressure cylinder. The temperature head is insufficient to drive heat through the cylinder in quantities required to check internal wastes; and the most wasteful surfaces, those of heads and port spaces, have no jackets to give even slight benefit. On the low-pressure cylinder, with a difference of temperature of about 80° Fahr., due to a difference of about 80 lbs. pressure inside and outside the cylinder at cut-off, the jacket gets useful work in to an observable but not large amount. With jacketed heads, this gain would presumably have been doubled; but no great gain is expected, ordinarily, from the use of the jacket on this class of engine. Whether it will pay to jacket or not, even here, however, depends, obviously, on the market price of fuel. Taking as here the gain to be about one pound of steam per horse-power per hour, and coal capable of evaporating eight pounds of water into steam per pound of fuel as worth $3 per ton, an engine of 100 H.P. would save in a year's work of 3,200 hours about twenty tons of coal, or $60, the interest on $1,000; or assuming the extra cost of the jacket on the low-pressure cylinder to be as much as $50, over 100% per annum. I suppose, however, that in this case the cost of the jacket may fairly be taken as simply that of the extra weight of cast iron used, or perhaps not over 300 lbs., at a cost of less than $10, on which the interest would be 600%—a very fair return. I do not imagine the risks on these small engines, arising from the addition of the jacket, need amount to anything worth considering. It requires a singularly small saving, as measured in percentage of steam and of fuel used, to make the introduction of the minor improvements of the steam-engine profitable. Were this engine driving a flour-mill or other establishment running night and day, this jacket would pay about 1,200% on the above basis, and the proprietor would find the borrowing of money at even old-fashioned rates in the West enormously profitable. It is these considerations, I take it, which determine whether it pays to jacket an engine—even a high-speed engine—or not.

This comparison was made with the engine working non-condensing and at its full power as rated condensing. Had the comparison been made under the conditions of intended operation, the effect of the jackets would have been affected to an important extent, and in the direction, I presume, of increased

efficiency. The desirability of jacketing would thus have been shown to be somewhat greater, and perhaps the high-pressure cylinder might then have gained something appreciable by its use.

The writer of the paper refers to my remark relative to the importance of draining the jackets back to the boiler, and not into the hot well or elsewhere. Where, as is often the case, the jacket-water amounts to 20%, with actively and effectively working jackets, the difference of something like 200 thermal units per pound, sometimes thus produced, amounts to from 2 to 4% of all the heat expended in the operation of the engine and of the fuel employed to develop that heat. That is to say: the cost of piping and traps to the boiler, from the jackets, would cost slightly more than the drainage apparatus to the hot well, and would save good interest on the cost of the engine, often, and thousands of per cent. on their own excess of cost. In cases like that here presented, the saving would be comparatively small, but even here it would pay well to conduct the jacket-water to the boiler. Assume 3% to be the average saving here obtainable in ordinary working. Then this difference would be something less than 1% of the heat, and the interest on about $150 or $300, instead, as in the case just assumed, of $1.000 to $2,000, accordingly as the engine runs by day only, or night and day.

I notice that the illustration given of this engine shows a peculiar form of governor, one which belongs to what is coming to be known as the "inertia governor" type, and to which reference has been made in discussions reported in earlier numbers of the Transactions of the Society. If I am not mistaken, Professor Carpenter has obtained some interesting data relating to the method and the perfection of this inertia action, in this case, and perhaps in others. It would be a contribution to our knowledge in a comparatively new field, could he find it convenient to give us this information. I have always believed that the adoption of the principle which characterizes these governors will prove the only satisfactory method of reducing that irregularity of engine noticeable with such sudden changes of load as are familiar to one accustomed to transmission of electrical energy for lighting or power, as it has already proved to be the best system on shipboard.

Mr. Jesse M. Smith.—I notice in Professor Carpenter's paper, in the comparison of the two engines (simple automatic and tan-

dem compound), that the compound engine is rated at 100 H.P., and is working under a steam pressure of 115 lbs. above the atmosphere to about 2 lbs. below the atmosphere. He explains that the air-pump was out of order and he was not able to get more vacuum. There is a range of pressure of 117 lbs. for the compound, while the simple engine is made non-condensing, and works through a steam pressure varying from 80 lbs. down to the atmosphere, or an effective difference of pressure of 75 lbs. Of course that acts in favor of the compound engine and against the simple. I note that he has made no comparison between the simple engine running non-condensing and the compound engine running non-condensing. That seems to me a very important comparison to be made, particularly as the low-pressure valve is driven by a fixed eccentric so that the point of cut-off is constant. Professor Thurston has drawn attention to the fact that in a compound engine driving a very variable load, as occurs in street railway practice, often the expansion line goes below the atmosphere in the low-pressure cylinder, in which case the low-pressure cylinder is acting as an air-pump and not as a working cylinder. Anyone who goes into a street railway power station and sees a pressure gauge attached to the receiver between the high and low-pressure cylinders in engines where the low-pressure valve is driven by a fixed eccentric, will very often see that the pressure in the intermediate chamber falls below the atmosphere. I remember in one particular case watching for fifteen or twenty minutes a gauge on the intermediate chamber which was figured about 15 lbs. vacuum and about 30 lbs. pressure. The needle for at least half the time was below zero, showing that the low-pressure cylinder was doing absolutely no work and was being worked as an air-pump. That condition can be corrected by actuating both the high and low-pressure valves by the governor; and, as Professor Thurston has said, this is being done by the Westinghouse Company, which seemed to give the inference that the Westinghouse Company is the only company that is doing it. There are others who are doing it, and I had occasion recently to take indicator cards from a small compound engine, 8 and 13½ x 12, rated at 60 H.P., running non-condensing, and driving an electric-light plant. I have four sets of cards here, one taken from each end of each cylinder, the four cards of each set taken simultaneously. The load varies from the friction of the engine and the dynamo producing no light (the brushes be-

ing set for full load). The power developed in the engine was successively 6, 34, 57, and 63 H.P. Throughout this entire range of load from 6 to 63 H.P., the pressure in the receiver remained between 29 and 30 lbs., and the expansion line in the low-pressure cylinder with this small load of 6 H.P. went just 1 lb. below the atmosphere. As soon as any load whatever was put on the dynamo, even that disappeared, so that for the regular working of the engine the expansion line never went below the atmosphere. What is more remarkable, the load divided itself almost exactly between the two cylinders throughout this entire range. I present the cards here with the data on them (Fig. 194 *et seqq.*):

COMPOUND NON-CONDENSING.

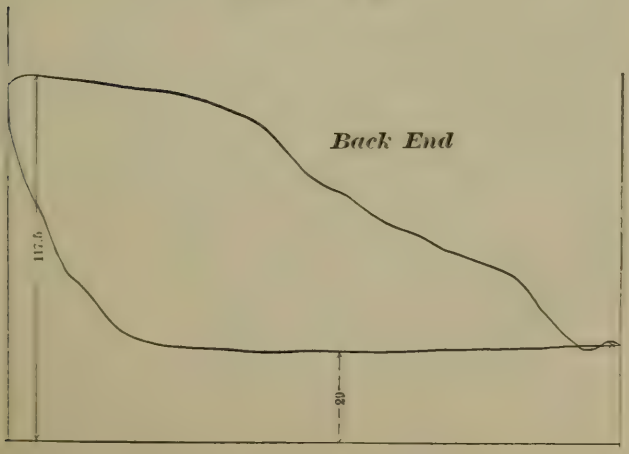
8 and 13¾ by 12.

Steam	119
Spring	60 high pressure.
Spring	20 low pressure.
Average revolutions per minute	242.5
Average indicated horse power:	
Back end, high-pressure cylinder	16.495
Crank end, high-pressure cylinder	15.615
Back end, low-pressure cylinder	16.073
Crank end, low-pressure cylinder	15.140
Total indicated horse power	63.323

LOAD.

Dynamo	335 amperes
	111 volts.

M.E.P. = 46.83



COMPOUND NON-CONDENSING.

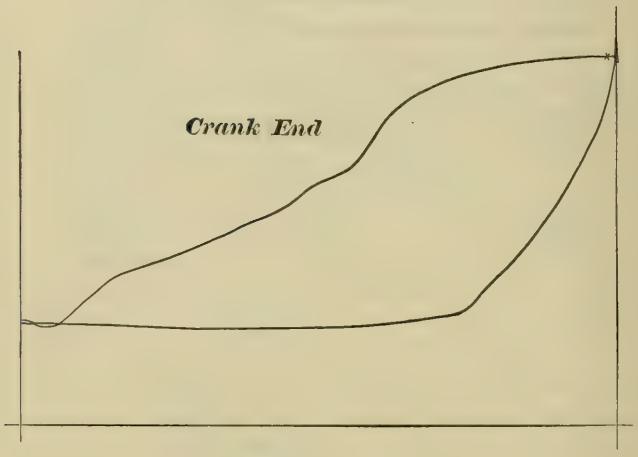
8 and 13¾ by 12.

Steam in chest	119
Spring	60 high pressure.
Spring	20 low pressure.
Average revolutions per minute	242.34
Average indicated horse power :	
Back end, high-pressure cylinder	14.72
Crank end, high-pressure cylinder	13.88
Back end, low-pressure cylinder	14.71
Crank end, low-pressure cylinder	14.00
Total indicated horse power	57.31

LOAD.

Dynamo	308.5 amperes.
	110 volts.

M.E.P. = 45.34.



COMPOUND NON-CONDENSING.

8 and 13¾ by 12.

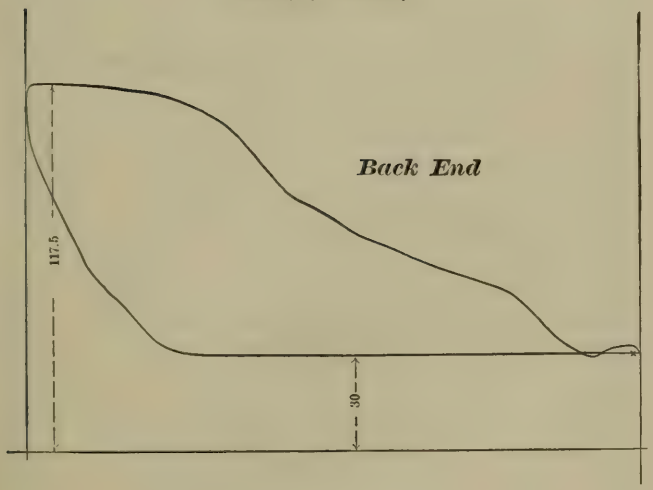
Steam 120
Spring..... 60 high pressure.
Spring..... 20 low pressure.
Revolutions per minute 248

Average indicated horse power, back, high-pressure cylinder.....	0.428
Average indicated horse power, crank, high-pressure cylinder	1.789
Average indicated horse power, back, low-pressure cylinder.....	1.714
Average indicated horse power, crank, low-pressure cylinder	2.431
Total indicated horse power	6.362

LOAD.

Engine with belts off.

M.E.P. = 39.25.



COMPOUND NON-CONDENSING.

8 and 13¾ by 12.

Steam	120
Spring	60 high pressure.
Spring	20 low pressure.
Revolutions per minute	247

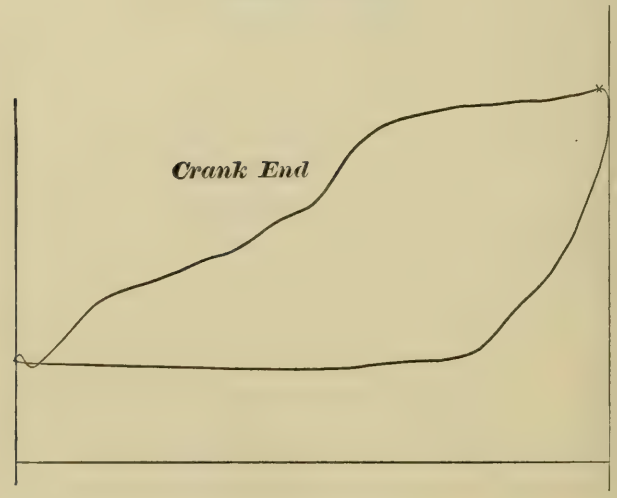
Average indicated horse power :

Back end, high-pressure cylinder	8.686
Crank end, high-pressure cylinder	8.996
Back end, low-pressure cylinder	8.303
Crank end, low-pressure cylinder	8.231
Total indicated horse power	34.216

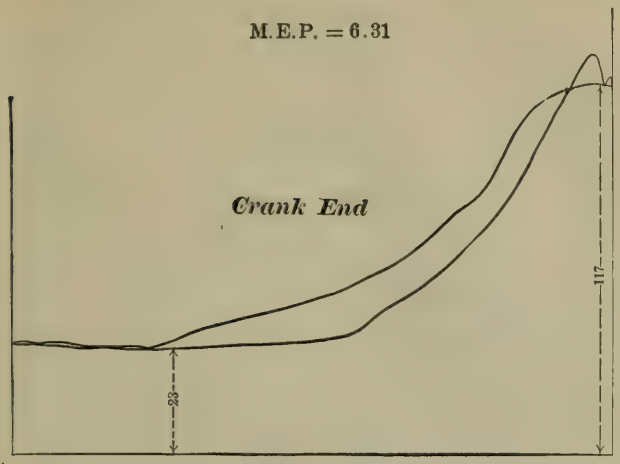
LOAD.

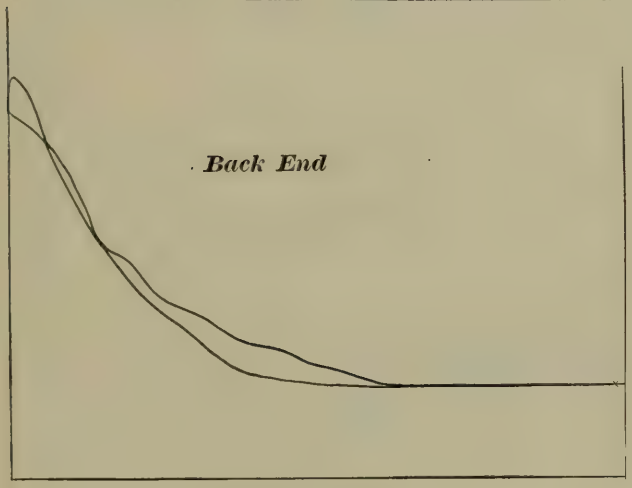
Dynamo	160 amperes.
	113 volts.

M.E.P. = 38.10.

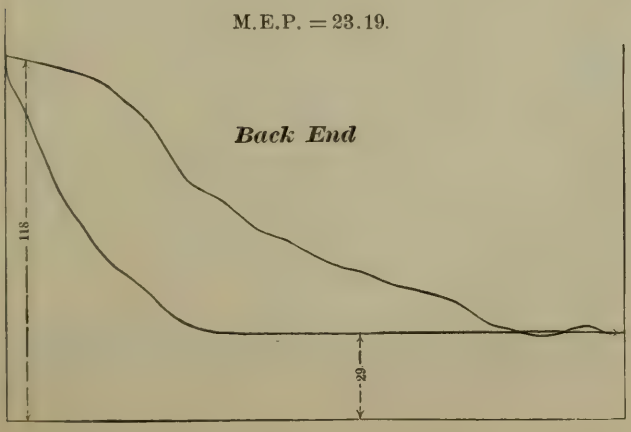


M.E.P. = 6.31

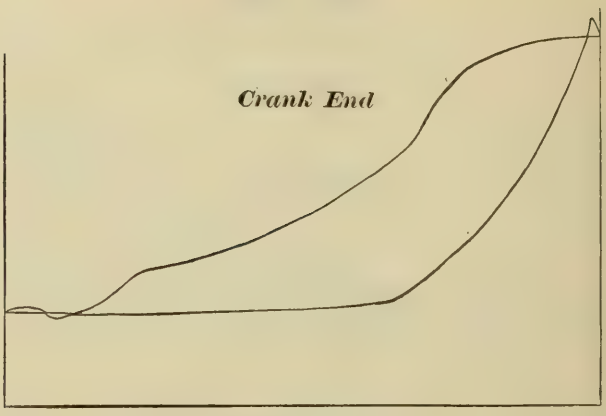




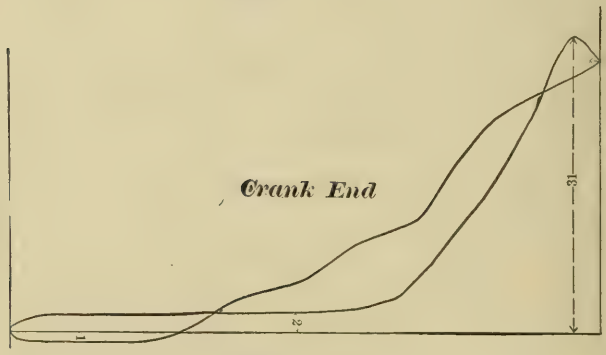
M.E.P. = 23.19.



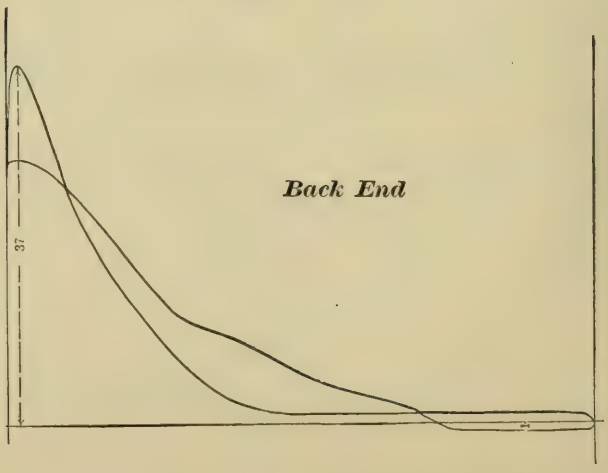
M.E.P. = 24.60.



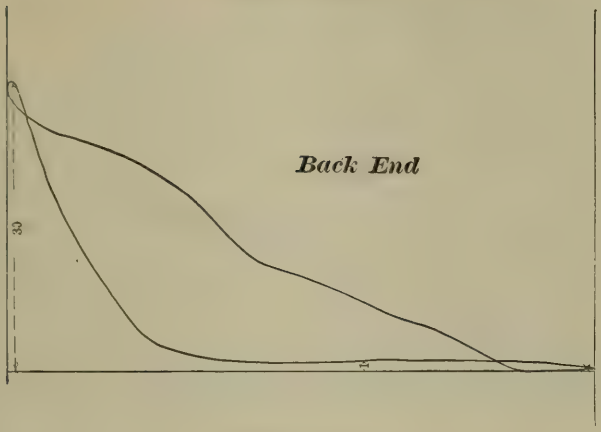
M.E.P. = 1.49.



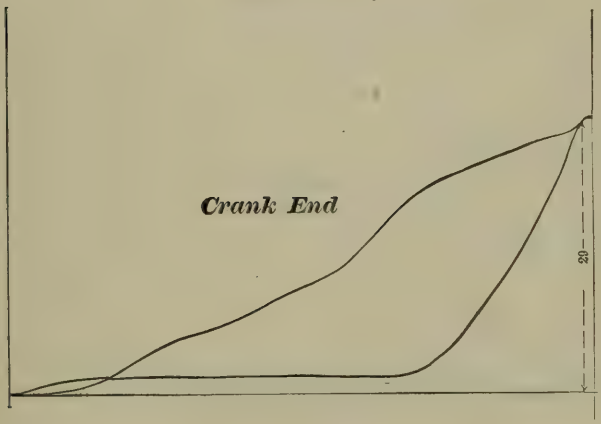
M.E.P. = 1.33.



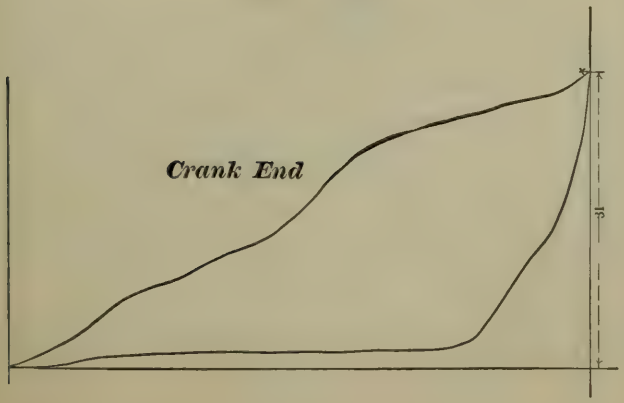
M.E.P. = 7.31.



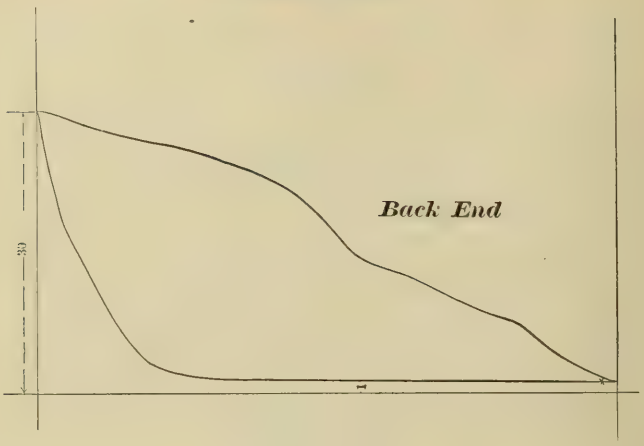
M.E.P. = 7.50.



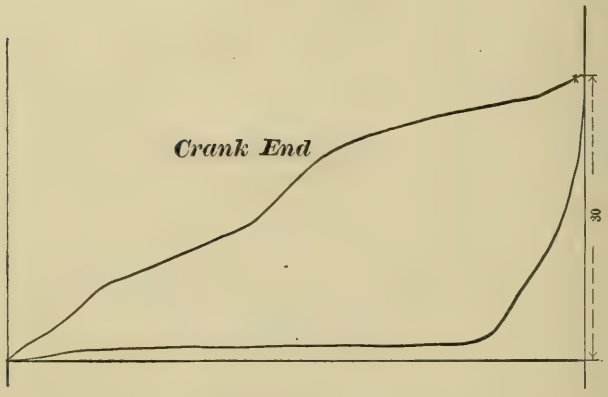
M.E.P. = 13.10.



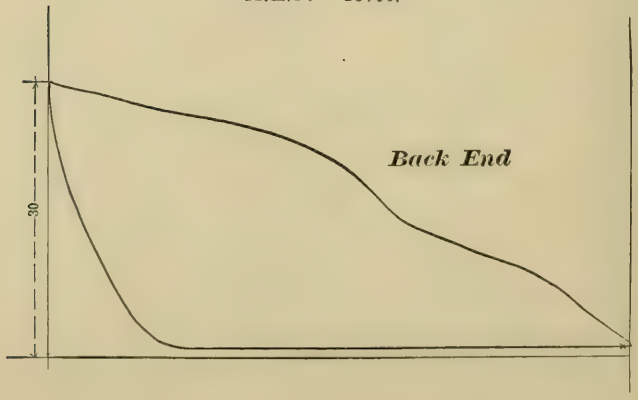
M.E.P. = 13.44.



M.E.P. = 14.30.



M.E.P. = 15.00.



The Rev., I.H.P., and load written on these cards is the average in each case of several sets taken under like conditions.

Mr. W. C. Kerr.—While this paper under discussion primarily concerns steam-jacketing, I wish to call further attention to a point briefly indicated by Mr. Jesse Smith, regarding the performance of the engine under variation of load.

On page 434 there is a chart giving water rates under varying load, and by accompanying data it will be seen that the condenser gauge showed 22″ vacuum for the tests plotted in one curve, and 23.5″ for the tests plotted in the other. This chart shows a wide range of horse-power—from about 25 to 125. Again, on page 435, the chart covers a variation of power on the compound condensing engine, corresponding to a range of 4½ expansions to 16 expansions.

Turning to the tables appended we find they only cover non-condensing service and practically constant load. On page 442 the variation is only from 99.2 to 107 H.P. On pages 443 and 444 the variation is only from 99.5 to 116.9. On pages 445 and 446 the variation is from 105.1 to 120.7. Thus the records in this instance cover very completely in the efficiency charts the operation of a compound engine when condensing, running through a wide range of power, while the tables appended are the records of the same compound engine non-condensing kept very near its rated load.

The experience of the past few years in the placing of thousands of compound engines in service has shown that, especially in the highest grades of engineering, to which these engines are apt to be applied, by far the larger number are required to operate non-condensing, not only under varying loads, but under variations much greater than have commonly obtained in the past. Hence, it now becomes especially desirable that when exhaustive tests are conducted on engines of this character, record should be made of the variation of efficiency under wide ranges of load when the engine is non-condensing, in order that the method of steam distribution used may be judged in the light of one class of service which the engine is most likely to meet. Similar remarks may be made regarding the necessity for testing such engines under different steam pressures.

On page 436 a chart is given, showing relative efficiencies of simple and compound engine under varying load, ranging

from about 25% to 115% of rated capacity; but I understand from the accompanying data that the compound was allowed a small vacuum, nearly 5 lbs., which would have a marked beneficial effect upon its efficiency, especially when the load was small. I mention this matter not to criticise, but to emphasize the importance in work of this nature to record the performance of compound engines when working entirely without vacuum or against the normal pound or two back pressure; for in the rapid development of the commercial compound engine as we see it about us to-day, most of the difficulties or failures which have been met, lie in the want of recognition of the necessity of such engines to maintain a nearly uniform efficiency when working over a wide range of load and steam pressure non-condensing.

Mr. Geo. I. Rockwood.—Professor Carpenter's experiments, as recorded in this paper, are very interesting to me in so far as they serve to establish the range of efficiency of the modern high-speed compound engine with change of load. Although worked under such widely different loads, the variation in the economical performance of this engine shown by the curve of efficiency in Fig. 174, is noticeably slight, and in this respect these trials are corroborative of certain results recently obtained in a series of economy trials of a slow-speed compound engine of somewhat unusual design, a description of which has been laid before the Society previously. The chief peculiarity of its design lies in the particular ratio of cylinder and receiver volumes adopted. The engine in question had been tested a number of times, four of these tests having been reported to you; but during the fall of this year further trials were carried out, there being a considerable amount of money to be invested in an engine of this class of unusual size, and the buyer being, naturally, interested to prove precisely the accuracy of those tests which seemed to show so excellent a performance.

In order, therefore, that this later investigation might be especially careful and accurate, and that a perfect check might be had on the feed-water and jacket-water measurements, a weir of solid and true construction was placed in position to measure the overflow from the air-pump. High grade thermometers, placed in the injection pipe close to the condenser and in the air-pump overflow, gave the increase of temperature of the injection water due to the condensation of the exhaust steam, and

thus it was possible to measure independently the amount of heat supplied to the engine by the boiler, and also the flow of heat through the engine.

The Ashcroft Manufacturing Co., of New York, kindly loaned the speaker the indicators used in measuring the power developed by the engine. For the measurement of the weir water, the Holyoke Water Power Co. very kindly loaned us their hook-gauge. One of Professor Peabody's superheating calorimeters was used to determine the moisture in the steam. I will read the table giving the general data and the water consumption for the two trials, called *a* and *b*; the first one, *a*, being made when but a part of the load of the mill was operated by the engine, the average indicated horse-power being about 148, and the second one, *b*, being made when the load was about 193 H.P.

GENERAL RESULTS OF THE TESTS.

Test.	*A.*	*B.*
Duration, hours	5 (7 to 12.)	5 (1.15 to 6.15)
Revolutions, per minute	80.	79.
Average steam-pipe pressure, pounds	143.	143.5
Average vacuum in exhaust pipe, inches	25.9	25.4
Average temperature of injection	66.°	66.7°
Average temperature of discharge	82.8°	90.5°
Pounds water discharged over weir per hour	102,633.	96,752.
Pounds jacket water per hour	322.	367.6
Pounds water weighed into boiler per hour (corrected)	1,953.8	2,524.0
Average indicated horse-power	148.23	193.68
Pounds water per I.H.P per hour	13.18	13.03
Per cent. of moisture in steam	1.33	1.44
Pounds of steam per I.H.P. per hour	13.00	12.85
Superheat of low-pressure receiver steam	39°	29°

Of course, in a given time the total heat of the steam passing through the cylinders added to the latent heat of the steam condensed in the jackets should equal the heat passing into the condenser plus the heat equivalent of the work done plus the heat radiated. In both of these tests such care was taken by the persons engaged in making the different observations that in each we were able to establish from the data obtained a practically true thermodynamic equation between the thermal units supplied to the engine as measured at the boiler and jackets, and the units which disappeared to produce work, radiation, and to raise the temperature of the injection water. I will read

the table showing the heat units consumed per I.H.P. per minute, reckoned both from the boiler measurements and from the weir measurements, for each trial:

Boiler Tests.	*A.*	*B.*
B. T. U. from boiler in saturated steam through cylinders (reckoned from temperature of the overflow)	210.7	210.34
B. T. U. of latent heat of jacket steam	30.1	27.14
Total B. T. U. per I.H.P. per minute supplied to engine	240.8	237.48
Weir Tests.	*A.*	*B.*
B. T. U. rejected into weir	190.9	193.6
B. T. U. converted into work	42.4	42.4
B. T. U. wasted by radiation	6.0	4.6
Total B. T. U. per I.H.P. per minute passed through engine	239.3	240.6

These figures show that for quite a wide variation in load, the economy of this engine was substantially the same per horse-power of work done. They also show, I think, a very high economy—an economy which we usually think is almost impossible to attain. Probably no triple expansion engine has ever done much better. There remains absolutely no question in my own mind about the general accuracy of our original tests; but of course the irresistible conclusion that I come to is that the triple expansion engine is more of a delusion than an advantage.

Mr. Jesse M. Smith.—Before that question is dropped I would like to have the gentleman explain why it is that on the ocean the single cylinder has given way to the compound and the compound to the triple, and the triple is now about to give way to the quadruple.

Mr. Rockwood.—I am not sure that question is really germane. I think not. The multiple cylinder engine owes its economic advantage over the single cylinder engine entirely to the increased number of expansions which may be used without adding to the loss by "cylinder condensation." The two-cylinder high-speed compound as commonly designed, uses, as Professor Carpenter shows, about 18 or 19 lbs. of steam per I.H.P. per hour. The best results which manufacturers of Corliss compounds will guarantee is about 16 lbs., while 13 lbs. is about as good as the best triple expansion Corliss engines have done; yet here is a case where a two-cylinder compound has done even better than 13 lbs.

For the benefit of those who may not recall the sizes of the

cylinders of this engine, I will add that they were practically 12″ and 28″ x 36″. A 16″ x 36″ intermediate cylinder could be used when desired, by connecting its valve gear to the other valve-rods and by opening and shutting certain valves, which thus changed the engine from a bi-compound into a tri-compound. When all the conditions were identical, except that three cylinders instead of two were employed, the economic result was also unchanged. Now the advantage of this compound over ordinary compounds arises from the fact that the low-pressure cylinder, instead of being but 20″ or 22″ in diameter, as is common, is the equivalent of 28″ in diameter, which permits a much greater number of expansions to take place.

Mr. Fred'k A. Scheffler.—I find on page 440, under the set of tests made of the simple automatic engine —non-condensing— the average pressures taken from the indicator diagram, shown at the bottom of the page, of the admission, release, and back pressures. I also find the average indicated horse-power of the test at the top of the page given as 75.85, and steam used per horse-power is 31.1 lbs. This, I understand, is the average result of the actual steam used in the engine, as measured through the surface condenser.

Out of curiosity, I calculated the water consumption, as shown by the average of diagrams, using the release pressure, absolute 33½ lbs., in order to compare same with the measured water consumption. I was very much surprised with the result of this comparison. If the average absolute release pressure is 33½ lbs., and the clearance is 8.75%, the quantity of water consumed, as shown by the diagram, is 31.7 lbs. per horse-power per hour, if the card shows 75.85 H.P., which I understand was the case. I have usually found that the amount of water shown by the indicator diagrams of an engine is from 20% to 30% *less* than the actual amount of water used, and the percentage varies with certain conditions; the amount which cannot be measured by the indicator card being lost in leaky valve, leaky piston, but largely surface condensation in the cylinder and heads.

I do not see how it is possible for an indicator card to show exactly the amount of water used, which it apparently does in this case; in fact, the indicator card shows a trifle *more* than the actual average water consumption, the latter being 31.1 lbs., and the former 31.7 lbs.

It seems to me that there must be an error in either the

average release pressure given, or in the measured water consumption, or the indicated horse-power.

I have gone all over my figures carefully, and cannot find any errors.

Mr. Geo. A. Hill.—There seems to be an omission in the tests recorded, which to my mind detracts much from the value of this paper.

At the present time there is a deal of controversy as to the relative merits of the simple and compound engine, when run non-condensing under variable loads, and also as to the relative merits of having the low-pressure cylinder valve, with an automatically adjusted cut-off, or with a cut-off adjusted for the average duty, and remaining the same for all variations of load.

Theoretically, we have no trouble in showing that the compound non-condensing engine, with the steam admission to both cylinders automatically controlled, will give a more economical result than the simple engine, provided the initial steam-pressure is near 75 lbs. or above, and the power required from the engine as an average is above say 50 H.P.; but practically it seems to be difficult to get makers to recognize these points, as witness the engine tested, in which the low-pressure admission was adjusted for the average duty; and, consequently, any set of tests may fairly be considered as incomplete, which do not give some data that will assist us to determine it finally, practically, as well as theoretically.

In paper 494, by Mr. Rites, the theoretical side of this question is well given. I also know of one trade catalogue which treats of it, and there have been several articles by Mr. Wm. Lee Church in the *Electrical Engineer* in the same line. My own observation has confirmed me in the belief, that a compound engine which does not automatically govern on both cylinders, and has to work under a variable load, is far less economical than a simple engine. I have no doubt but that there are plenty of members of the society who have had the same experience.

The *Electrical Engineer* during the past year has had a number of articles by practical men, raising this very point, many of them going so far as to say that unless the compound engine can be run condensing, and under an approximately steady load, it will be less economical than the simple engine.

In view of these facts, it seems to be a pity that Mr. Carpen-

ter's paper did not take in the greater range of load, non-condensing, so as to have this much more data to work with.

Referring to the curves given in Fig. 176, it seems to me that they are not fairly representative of the compound, as the curve is plotted from too few determinations, too widely separated, and it seems to me should be flatter, until a point is reached near the 20% limit, from which the curve should rise rapidly to the 15% point, and then from there up should go nearly vertical. I have no figures of steam consumption to substantiate this, but think that it is fairly deducible from paper 494, in which the consumption of steam from actual tests is given as being practically the same in the same engine, from 80 to 210 H.P., and only increased 11% for 50 H.P., and from the guarantees given by the builders of the Saco & Biddeford Railroad Company's new plant. This plant is described in the *Electrical Engineer* of November 28, 1892, and the duty of the compound non-condensing engines is there given as 25 lbs. of steam at 125 lbs. pressure per hour for full load, and 28 lbs. for one-third load.

I trust that it will be possible to obtain data from the Saco & Biddeford plant above referred to, as street railway service represents an extremely wide range of duty, and the actual results could not fail to be of value.

*Prof. R. C. Carpenter.**—I am much pleased at the interest manifested in the paper, and as there was a call in the discussion for more data relating to the test of the compound engine, I have supplied an abstract of the log, which I may say was unintentionally omitted from the main paper. I have also added, on page 447, head and crank diagrams of the simple engine, corresponding to No. 4 of the log, as given on page 440. These diagrams are super-imposed, in order to save space and for purposes of comparison, but they were taken simultaneously by separate indicators; as will be seen by measuring the diagram, the steam accounted for by it is equal to 24.6 lbs. on head end, and 24.2 lbs. on the crank end, per I.H.P. per hour; this amount is 79% of that actually obtained during the test. There is very little to be said in answer to the discussion, and very little that requires answer. I will, however, sum the discussion up, and then make a few statements regarding a general method of expressing the change of economy with variation in load.

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* Author's Closure under the Rules.

The discussion in many places tends to leave the strict province of the paper, and references are made in the discussion by Dr. Thurston, Mr. Smith, and Mr. Hill, to the better performance with low loads when the low-pressure valve is actuated by the eccentric. From the nature of the engine, it was in this test impossible to secure data of that character, and the writer wishes to express no opinion whatever regarding the relative merits of these two styles of construction. I have, however, data of engine tests of another engine, which differs principally from the one tested in that point of construction, and I hope to be able to present the matter at a later meeting.

Dr. Thurston gives an excellent summary of the paper, and calls attention to previous tests of this character; he also deduces the probable profit from the use of the steam-jacket, and his discussion rounds out the paper very fully. Mr. Smith and Mr. Kerr each call attention to facts stated in the paper, which might otherwise be overlooked, but for which there was no peculiar claim made in the paper; namely, the greater range of working temperatures of the compound as compared with the simple, which accounted for a portion of the gain, and that the tests for variation of load were made only with the compound engine run condensing. The omission of the log of the test of the compound condensing engine which Mr. Kerr refers to has, as already remarked, been corrected. The facts as stated represent very fully the condition of the tests; and as the method of testing was described in the paper, no further discussion is required. As no comparisons were made of the economy of a simple and compound engine, but simply of the relative variations in that economy, the difference in pressures seems not to be of moment. The remark of Mr. Smith is, however, of great practical value, and should not be overlooked; thus two perfect (*i. e.* engines whose loss is measured by the thermodynamic efficiency) engines, one working between the limits of 344.1 Fahr. and 162.3, as was the case with the compound, and the other working between the limits of 322 and 212 Fahr., as was the case with the simple, would require in the first case 10.7, and in the second case 15.5 pounds of water per I.H P. per hour. This is about as great a variation as was actually found, and compared with those numbers, the efficiency of the compound was about 59.7 and the simple 50.5%.

It would seem to the writer that the proper comparison of

the work of an engine is that with a perfect * engine working between the same limits. A table is given later, showing the performance of a perfect engine. The discussion of Mr. Rockwood is very interesting, and some valuable facts are given which seem to corroborate the results obtained, and exhibited in the paper. Mr. Hill refers to the need of data, regarding the proper position of the low-pressure valve, which I hope to take up in a later paper, but which did not come within the scope of the present test.

In regard to the shape of the curve, I decidedly do not agree with Mr. Hill; and as he gives no reasons whatever for his opinion, I do not see that it should be given any particular weight. The curve does, it seems to me, represent the results of the series of tests very well, and there is a sufficient number to form a decided opinion as to its general form; I do not, however, claim that a greater number of tests would not modify it to some extent, but I fully believe that difference is small, and that the true curve lies, not as Mr. Hill says, but on the opposite side of the curve given.

In regard to that discussion concerning the water accounted for by the indicator, I do not know of the method employed by the gentleman, but, since seeing his remarks, I have had several engineers make computations of the steam shown by the diagram; and while several methods have been employed, the results in every case agree substantially with those stated. The diagrams are given, and the accuracy of the results can readily be checked.

Since the paper was written, the writer has given the question of change of economy with variation in load some attention, and from this draws the conclusion, that all the results which so far have been considered can be very closely represented by a single equation.

This equation is, of course, empirical, and is based on a comparison of the results actually attained with those that would be obtained by working the steam within the same limits of pressure in a cylinder which was absolutely not permeable by heat; such an engine is here termed a *perfect* engine, for the basis of comparison. The efficiency of such an engine is the same as the thermodynamical efficiency of the actual engine,

* The term "perfect" as used here, refers to an engine whose efficiency is the same as the thermodynamic efficiency.

working between the same limits. The steam required for such an engine per I.H.P. per hour, which for brevity we will term the *water-rate*, is equal to

$$2545 \div (\lambda - q_0)e,$$

in which λ is the heat contained in one pound of the entering steam, q_0 the heat of the liquid at temperature due to back-pressure, e the thermodynamic efficiency. It will be noted that the perfect engine, as defined above, does not work in the *Carnot* cycle, but accords somewhat more with the actual engine.

The following table is of value as showing the amount of steam per I.H.P. per hour within various limits required for this perfect engine:

POUNDS OF DRY STEAM AND B.T.U. PER I.H.P. REQUIRED BY THE PERFECT ENGINE.

Steam Pressure Absolute.	Temp. of Steam Dry, Fahr.	Back-Pressure 14.7 pounds [212°].			Back-Pressure 5 pounds [162.3°].		
		Thermal Efficiency %	B. T. U. per I. H. P. per minute.	Dry Steam per I. H. P. per hour.	Thermal Efficiency %	B.T.U. per I.H.P. per minute.	Dry Steam per I.H.P. per hour.
25	240	2 6	1620	100.05	10.9	388	22.8
30	250.3	5.35	740	48.8	12.4	340	20.0
40	267.1	7.55	560	34 2	14.7	287	16.8
50	280.9	9.2	465	28.0	15.95	266	15.4
60	292.5	10.55	400	24.0	17.25	245	14.2
70	302.7	11.8	364	21.8	18.4	230	13.2
75	307.4	12.4	340	20.6	18.9	224	12.85
80	311.8	12.95	328	19.7	19.5	217	12.5
90	320.0	13.85	306	18.3	20.5	206	11.85
100	327.6	14.7	288	17.3	21.1	200	11.5
125	344 1	16.4	259	15.5	22.7	187	10.7
150	358.2	17.85	240	14.1	24 0	177	9.9
175	370.6	19.1	221	13.0	25.1	169	9.55
200	381.7	20.2	208	12.4	26.2	162	9.20

The steam required for any engine may evidently be considered as made up of two parts.

First: That required to do the work, which must equal that required by a perfect engine working within the given limits of temperature.

Second: That required to overcome the wastes of the engine.

Of these quantities the first part is a constant for each unit of work performed; the second is variable, and the laws which govern its distribution are no doubt complex; at least, no theo-

retical statement of these laws has been given by any writer known to the author.

The writer has made several comparisons with two formulæ expressing these wastes for engines working under a great diversity of condition, and would respectfully call attention to the results so obtained as forming two practical rules for expressing the economy of an engine under various conditions of loading.

The hypotheses made were, *A*, that the wastes vary as the square root of the ratio of work done, a certain known load giving the minimum result which is supposed known; *B*, that the wastes vary as a function of the hyperbolic logarithm of this ratio.

The formulæ considered were as follows:

$$y = b\sqrt{x} + p \qquad (A)$$

$$y = b\sqrt{1 + (\log x)^2} + p \qquad (B)$$

In the above formulæ, p is the water rate of the perfect engine as given in the table preceding; x is the ratio of the work (expressed in I.H.P.) at best actual rate to that for any given case or its reciprocal; it is in any case to be taken greater than 1; b is the difference between the best actual water rate and that required for a perfect engine; y is the water rate required.

The curves represented by these formulæ differ from each other a good deal for values of x greater than 4, but are in substantial accord for small values of x. From a geometrical standpoint the curve has two branches about the axis of y and one branch about the axis of x. In practice we use only one of these branches, and we have so defined x that we construct a curve on either side of the axis, which joins at a point $x = o$, $y = p$.

As it was only sought to get a simple mathematical formula that could be readily applied, an analysis of the form of curve does not seem to be essential.

An application of these formulæ to several cases is made:

1st. The simple engine reported in the paper. In this case we have absolute steam pressure 91.4, best performance 75.9 I.H.P., best water rate actual 30.95 lbs., corresponding water rate of a perfect engine 18.45 lbs. Hence,

$$b = 30.95 - 18.45 = 12.5.$$

And we have applying to this engine:

$$y = 12.5 \sqrt{x} + 18.45 \qquad (A)$$

$$y = 12.5 \sqrt{1 + \log x^{.2}} + 18.45 \qquad (B)$$

Indicated Horse Power	Value of x	Water rate by formula A	Water rate by formula B	Actual by Test.*	Actual I.H.P.	Results Water rate.
18.9	4.0	43.4	45.4	45		
21.6	3.5	41.8	40.7	43	20.8	44.1
25.2	3.0	39.1	37.5	39.5	25.1	39.7
30 3	2.5	37.1	35.2	35.5		
37.9	2 0	36.1	33 7	34.3	37.1	35.2
42.0	1.8	35.1	33.15	33.2	41.4	33.6
47.5	1.6	34.1	32.5	32.3		
50	1 5	33.8	32.4	32.0		
60.5	1.25	32.4	31 8	31.1		
64	1.2	32.1	31.7	31.0	63.1	31.5
69	1.1	31.5	31.3	31		
75.8	1.0	30.9	30.9	30 9	75.8	30.9
83.4	1.1	31.5	31.3	31.0	83.4	30.9
91 0	1.2	32.1	31.7	32	88.0	32.2
94.7	1.25	32 4	31.8	32		

* Interpolated values from curve, Fig. 171.

COMPOUND CONDENSING ENGINE.

As described in paper. J. H. McEwen Manufacturing Company. Results compared with formu æ. Best results 19.2 lbs. at 88.8 I.H.P. Engine without jacket.

$$y = 8.5 \sqrt{x + 10.7} \quad (A). \qquad y = 8.5 \sqrt{1 + \log x^{.2} + 10.7} \quad (B).$$

I.H.P.	Ratio x.	Results by formula A.	Results by formula B.	Actual by trial.
56.	1.58	21.4	20.7	22.1
70.3	1.26	20.2	19.8	21.3
88.8	1.00	19.2	19.2	19.2
97.8	1.105	19.7	19.4	19.8
119.3	1.32	20.5	19.9	20.1

Same engine with jackets. Best results 18.9 lbs. at 80.5 I.H.P. Absolute pressure 125.

$$y = 8.3 \sqrt{x + 6.6} \quad (A). \qquad y = 8.3 \sqrt{1 + \log x^{.2} + 6} \quad (B).$$

27.17	2.95	24.8	23.2	23.11
44.	1.84	21.8	20.4	20.7
61.03	1.32	20.1	19.6	19.69
80.5	1.00	18.9	18.9	18.9
95.1	1.18	19.6	19.3	19.1
100.6	1.32	20.1	19.6	21.7
118.4	1.46	20.6	19.9	20.3
126.	1.58	21.4	20.5	21.2

TRIPLE EXPANSION CORLISS ENGINE.

Test by Prof. C. H. Peabody. See paper read at New York Meeting, 1892. Absolute pressure, 140.5 lbs. Exhaust pressure, 3 lbs. Thermal efficiency, 30.2. Water per I.H.P. required by the perfect engine, 7.7 lbs. Best actual consumption, 13.74 lbs.

Equation $y = 6.14\sqrt{x + 7.7}$ (*A*).

I.H.P. developed.	Water rate, formula *A*.	Actual water rate.
140.79	14.1	13.82
125.37	13.74	13.74
114.6	14.05	14.36
105.3	14.28	14.48
99.2	14.74	14.78
78.32	15.35	15.13
67.45	15 95	16.0

These examples can be extended indefinitely, but I beg your indulgence to a comparison with the Westinghouse engine, non-condensing and condensing, as given on the cover pages of their trade pamphlet.

The results there are given for brake horse-power only, and we will assume that the indicated horse-power is in each case ten greater than that of the corresponding brake horse-power; a few horse power more or less will not sensibly affect the ratios on which the results depend, so it is not material whether the actual friction horse-power be seven or twelve.

NON-CONDENSING ENGINE.

Gauge, 120. Absolute, 135. We have

$y = 7.75\sqrt{x + 15}$ (*A*). $y = 7.75\sqrt{1 + \log x^2 + 15}$ (*B*).

Brake horse-power.	Total height steam.	I.H.P. developed.	Value of ratio x.	Water Rate.		
				Formula *A*.	Formula *B*.	Actual.
200	4,788	210	1.0	22.75	22.75	22.75
160	4,088	170	1.23	23.6	23 3	24.1
130	3,161	140	1.5	24.5	23.7	22.6
100	2,557	110	1.91	25.7	24.2	23 2
90	2,386	100	2.1	26.2	24.6	23.9
70	2,058	80	2.62	27.6	25.7	26.2
40	1,602	50	4.2	30.8	31.7	32.0

NON-CONDENSING ENGINE.—*Continued.*

Same engine, 100 lbs. boiler pressure by gauge.

Equation $y = 7.2\sqrt{x + 16}$ (*A*). $y = 7.2\sqrt{1 + \log x^{c} + 16.6}$ (*B*).

Brake horse-power.	Total height steam.	I.H.P. developed.	Value of ratio x.	Water Rate.		
				Formula *A*.	Formula *B*.	Actual.
160	4,032	170	1.	23.8	23.8	23.8
130	3,440	140	1.21	24.3	24.3	24.4
100	2,775	110	1.54	25.5	24.7	25.2
90	2,547	100	1.7	26.0	24.9	25.4
70	2,154	80	2.125	27.1	25.7	26.8
40	1,572	50	3.4	29.9	29.5	31.4

WESTINGHOUSE ENGINE.

14 and 24 by 14. Compound condensing. 120 lbs. boiler pressure.

$y = 5.2\sqrt{x + 12}$ (*A*). $y = 5.2\sqrt{1 + \log x + 12}$ (*B*).

Brake horse-power.	Water rate per brake H.P.	Total water.	I.H.P.	Ratio value of x.	Water rate per I.H.P.		
					Formula *A*.	Formula *B*.	Actual.
200	19.62	3,924	210	1.91	19.2	18.3	18.75
160	18.86	3,018	170	1.55	18.45	18.0	17.8
130	18.38	2,389	140	1.27	17.8	17.65	17.1
100	19.14	1,914	110	1.00	17.2	17.2	17.4
70	19.08	1,386	80	1.375	18.6	17.7	17.35
40	22.9	916	50	2.2	19.7	18.6	18.32

Same engine, 100 lbs. boiler pressure.

$y = 4.69\sqrt{x + 12.85}$. (*A*). $y = 4.69\sqrt{1 + \log x^{c} + 12.85}$. (*B*).

200	22.53	4,506	210	2.625	20.4	19.4	21.4
160	20.02	3,203	170	2.125	19.7	18.8	18.85
130	19.56	2,543	140	1.75	19.0	18.3	18.2
100	19.44	1,944	110	1.375	18.3	17.95	17.7
70	20.05	1,403	80	1.0	17.54	17.54	17.54
40	23.12	925	50	1.6	18.7	18.15	18.5

The examples given show that the formulæ have an extended application to engines of varying classes, and that either one will give results which do not differ greatly from actual tests.

Formula A is much more simple in form than formula B, and is for this reason to be preferred; but it seems probable that for changes of load from $\frac{1}{4}$ to full, formula B is more accurate; but for extreme changes, say from $\frac{1}{50}$ to $\frac{1}{4}$, A gives results which accord well with the actual.

The practical conclusion to be drawn is this: that the variation of the mean economical engine due to change of load is much less than that of the more wasteful one. In any event the waste is obtained by comparison with the perfect engine.

DXXIV.*

VARIABLE SPEED POWER TRANSMISSION.

BY H. C. SPAULDING, EXETER, N. H.

(Member of the Society.)

If such an estimate could be made with any approach to exactness, it would be most interesting to know how many pairs of step pulleys are to-day in operation in the United States alone. Surely there are few mechanical contrivances more generally accepted and incorporated into every class of machinery for affording a simple and ready means of changing the speed either of the entire driven mechanism, or of one or more parts of it, independently of others. Yet their inherent defects are so well known as to call for hardly more than bare mention, in order that they may be borne in mind while considering the device presented below. Inability to produce speeds other than those predetermined by the ratios of corresponding steps; the limited number of such speeds except as obtained by large and unwieldy cones with an excessive number of radii, at a corresponding expense in stock and finishing cost; inconvenience of shipping belts except as applied to light work and without stopping the machine, or at least depriving it of driving power while the change is being made; enforced parallelism of driving and driven shafts;—all are considerations so thoroughly appreciated by practical engineers and designers, as to call for no extended comment. The demand for something which should offer the same advantages with fewer attendant drawbacks, has been partially met by a number of devices which have become more or less well known, in connection with various classes of machinery.

In spinning apparatus, speeders and fly-frames allow the use of continuous-element cones, the shafts being conveniently placed near together and parallel, while a continuous and

* Presented at the New York Meeting, November, 1892, of the American Society of Mechanical Engineers, and forming part of Volume XIV of the *Transactions*.

gradual change of speed is obtained by slowly and automatically shifting the belt from one end of the cones to the other. Were the required range of speed greater, however, or the change more rapid, the device would evidently not produce such satisfactory results.

In woodworking machinery the use of a wheel so arranged that it may traverse a driving disk, its edge thus attaining a speed corresponding to that of the disk at varying distances from its centre, has been tried with more or less; success but the frictional contact (theoretically a line only) is so slight that saw-dust or dirt of any kind, on wheel or disk, is liable to interfere with uniform action, while the axis pressure of both parts must be excessive, and the driven shaft varies its position with every change of speed, necessitating an extra link in the mechanical transmission, with a consequent friction loss.

The Evans friction cone has recently been applied to a number of problems of this character, but is open to the objections inherent in all continuous cones, while the shafts must be close together, and expert opinions differ as to the durability of the belting used, owing to the peculiar and rapidly recurring stresses to which it is subjected when in operation.

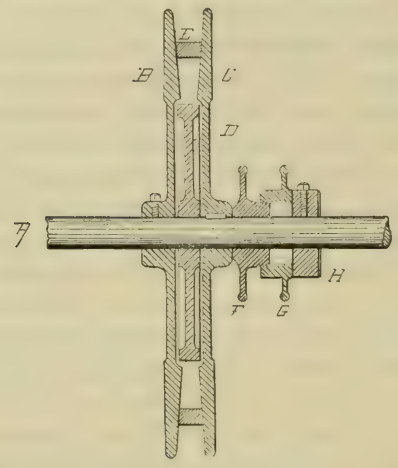
Without dwelling upon other devices for obtaining the desired results, we come to a type of apparatus which seems to the writer to overcome most of the difficulties noted, in a simple and effective manner, the invention of Mr. E. F. Gordon, Mechanical Engineer of the John A. White Company, of Dover, N. H. In the opinion of those most interested in its development, it is worthy of more extensive trial and investigation than has been or can in the immediate future, be given it in the line of machinery to which it is now being applied, and in presenting it to the Society it is hoped that its possibilities and limitations will thereby be more clearly brought out by actual demonstration.

Simply stated, the device consists of a deeply grooved pulley, split by a plane perpendicular to its axis, and dividing it symetrically, with means for varying the distance of the two parts one from the other.

Given a belt adapted for the purpose, it will, in running on such a pulley, lie nearer the centre as the two parts are more widely separated, and recede as they are brought nearer together. Such a pulley may be used on either the driving or

driven shaft, or both, and it is evident that the shafts may be at any practical distance apart, also that the greater the pull on the belt, the greater its hug and consequent freedom from slip. In some cases it is desirable to place a loose pulley between the two parts referred to, making a compact arrangement for starting, stopping, and varying speed, in the space ordinarily occupied by a single pulley of the usual style.

Fig. 181 shows such an adaptation of the device, with one of the many available arrangements for varying the working radius of the pulley. In the illustration, *A* is the shaft, *BC* the two halves of the pulley, *D* the idler, *E* the belt, *FG* hand

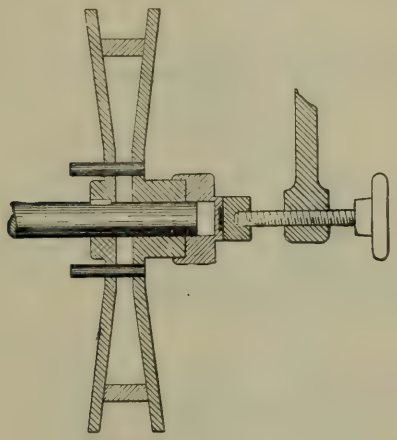


-FIG 181-

wheels, *H* a collar fast on the shaft. By the action of the belt, *B* and *C* tend to separate from each other, and since *B* is fast on the shaft, *AC*, which is splined on the shaft, and hence must turn with it, although free to move along it, is forced against *F*. The hand wheels, *F* and *G*, are free to turn on the shaft, but may be held at rest whenever desired. The hub of one carries a male screw, and the other a female, so that by altering the position of one on the other, they increase or decrease the distance between the collar, *H*, and the half of the pulley, *C*, thereby allowing *C* to recede to a greater or less distance from *B*, and determining the position of the belt, *E*, and its consequent speed relative to that of the shaft, *A*. It will be

evident that in this construction, when used as a driving shaft, the belt speed will become less and less as F is screwed into C, until C has so far receded from B as to allow the belt to drop on to the idler, P, when the driven mechanism will come to a standstill, to be gradually started again by the adjustment of F and G.

Fig. 182 shows a still simpler form, applicable when the pulley is located on the end of a shaft. In this case the loose pulley is omitted, it being assumed that only a speed adjustment is necessary, one part of the pulley being fast on the shaft, the other free, but loosely pinned to the first so as to rotate with



-FIG 182-

it, the working radius being determined by the adjustment of a hand screw.

The belt may be either round or nearly square in section, though for the most of the experiments so far made a narrow double-ply leather belt has been used, with the edge beveled to correspond with the angle of the pulley's face.

The construction shown in Fig. 182 has recently been applied to the feeding rolls of a 48″ band resawing machine in a way which illustrates its simplicity and adaptation to this class of work.

Fig. 183 shows the arrangement of parts, A being the split pulley, its shaft being driven by a link belt from a continuation of the lower band-wheel shaft, and supported by an arm, B,

swinging from this as a centre. The belt, *C*, drives the pulleys, *DD*, on horizontal shafts worm-geared to the axes of the feed rolls, the swing of the arm, *B*, compensating for the varying length of the belt, *C*, owing to changes either in position of the feed rolls, *E*, with reference to the saw, or in the working radius of *A*, the latter being determined by the position of a hand screw.

The diameter of the split pulley is 12″, the minimum working radius 3″, giving a linear speed to the surface of the feed rolls of from ten to thirty feet per minute. A double-ply belt 1 inch

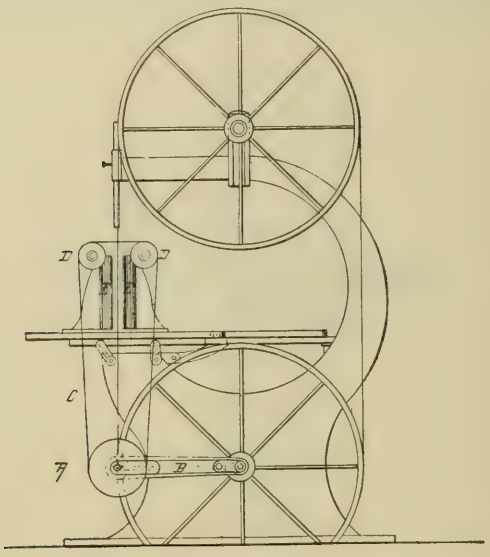


FIG 183

wide is used, and its power is such that if the stock be held firm, the slip occurs between it and the feed rolls (four in number, all geared, 18 inches long, 3 inches diameter), and not at the belt, as in the case of the usual style cone pulley formerly used with a machine of the same capacity.

No dynamometric tests have yet been made, but a pulley six feet in diameter is now nearly ready for careful investigation as to efficiency under widely varying loads and speeds. Should the results be satisfactory, the simplicity, compactness, reliability, and cheapness of the device would apparently warrant its extensive use by the engineering fraternity.

DISCUSSION.

Major M. P. Wood.—I would like to ask what kind of belt Mr. Spaulding is using—single, double, or triple—and about what horse-power has been transmitted?

Mr. Spaulding.—We use some double and some triple belts. We have not used the round belt to any extent, because in the experiments and in the machines already designed and now designing it is perfectly convenient for us to have the shafts parallel. In actual work we transmit not over 10 H.P. We have done some experimenting, and have already built a pulley of 6 feet in diameter, maximum radius, which we will try for much heavier service.

A Member.—Have you made any tests for friction?

Mr. Spaulding.—No carefully observed tests to amount to anything.

A Member.—Aren't you afraid of that?

Mr. Spaulding.—The inventor is not. That is all I can say.

A Member.—What becomes of the slack under wide variation?

Mr. Spaulding.—The slack may be taken up by an ordinary idle pulley, though in the machine shown in Fig. 183 it is taken up by the mere swing of the shaft and pulley about the driving shaft as an axis.

Mr. Oberlin Smith.—I would like to ask if this is not used sometimes with two of the pulleys so that the sums of the radii can be kept constant by making one larger and the other smaller.

Mr. Spaulding.—Yes, sir; that is an accidental omission on my part, but the paper really covers that by saying it can be used either on a driving or driven shaft or both. That would require a slight amount of calculation in designing a curved face instead of using the pyramidal form.

Mr. Jesse M. Smith.—It occurs to me, with the use of two pulleys, one on each shaft, that the pressure could be made automatically uniform by means of a spring acting on one of the pulleys so that it would accommodate itself, by variations of diameter, to the other, which can be moved by hand.

Mr. Spaulding.—We are now constructing a lathe on that principle, although it has not been tested yet, and I did not say anything about it for that reason.

Mr. Wood.—Have you been able to break the belt with it yet?

Mr. Spaulding.—We have not yet.

Mr. Oberlin Smith.—Will that belt flow out when you squeeze?

Mr. Spaulding.—Yes, sir; there seems to be no trouble about that at all. There is really no tendency for it to crowd in excessively. That form shown on page 481, while it is working under load, may be adjusted by the thumb and fingers very easily. The angle between the faces of the groove I cannot give you exactly. Of course the limits are rather wide and we have not made any very thorough tests regarding them. The angle is very nearly that shown in the cuts, and it has not seemed desirable to use any greater angle (nothing flatter) than that shown on this illustration.

Major Wood.—Approximating 5°?

Mr. Spaulding.—Something like that.

Mr. F. R. Low.—I saw last spring, at the works of the Skinner Engine Company, at Erie, a transmission similar in principle to that described in the paper. The cones were made interlocking and of such a pitch that the angle between their faces was about 90°. They were belted to a similar pair upon the driven shaft by a common single-ply leather belt some four inches in width, bent to fit the V groove made by the interlocking pulleys and kept in that shape by angle irons riveted onto its back. As one pair of cones was made to approach, the other pair separated, so that the sum of the radii was constant and the belt always of the right length. I think it was made to automatically change the rotative speed of a tool used to face off work, in order to preserve a constant tool speed with increasing diameters.

Mr. Oberlin Smith.—Some years ago I tried a similar device. I had two cones, with faces about 45°, with their axes each interlocking the other, just as one sometimes cuts a watermelon into two halves, except that the tongues and slots were parallel and bounded on their sides by axial planes. I varied the size from five or six to one very successfully, and used a rope belt in the interrupted 90° groove between the cones. I have not carried the matter any further and do not know how well the device would answer in practice with heavy work. It does not, however, have the feature that this one has of pinching the belt and thus probably getting a greater efficiency. It would be interesting, in considering this very ingenious device, to know what the loss of efficiency is by the side friction of the belt.

Mr. Spaulding.—There have been two or three devices some-

thing like this. But what seems to be an absolutely new feature is the combination of a loose pulley with the separable driving faces. There is also in the Patent Office a quite old patent showing a split pulley with a round groove for carrying a round belt or rope, and a loose pulley inside, but in that case there was no provision for changing the working radius. Mr. Gordon in this device seems to have reduced it to a practicable form comprising both valuable features.

Mr. Bancroft.—This device seems to be very much like the friction disk transmission invented by Dr. Coleman Sellers in 1861, in which there was a driving and a driven disk coupled by two clamping disks, the acting surfaces of these being portions of the surface of a sphere of relatively large radius. This arrangement makes an admirable feeding device, as a wide variation of speed can be obtained, nearly 24 to 1. It is, however, not efficient for transmitting power; some of our recent experiments show a loss from friction of from 50 to 75%, and I should suppose that this belt drive would have the same defect, though perhaps not to the same degree.

Mr. Henry L. Binsse.—I have had several years' experience with the Sellers friction disk; and I think that the inefficiency of the original forms of that device may be laid to incorrect design of the details. So far as I know, these disks were always used with a spring instead of positive pressure; and it is my belief that the materials used in their construction were not the most suitable. I have built over sixty machines with friction disks, all of which have proved perfectly satisfactory; and, had there been a great loss of efficiency, I think complaints would have been made, as the machines are rather delicate ones. Although I have made no actual measurements of the efficiency of my design, I feel very confident that the Sellers friction disks may be made fairly efficient. I think that the use of leather with a positive pressure will make that (the pulley) a very efficient device, and I think that if a spring be used the efficiency of the pulley will be diminished. Leather is one of the best materials, if not the very best, for the above purpose.

Mr. Green.—I should like to ask Mr. Spaulding if he has experienced any difficulty from the compression of the leather belt? I have used a similar device for varying speeds, using a round belt. I found that the belt would compress, necessitating an adjustment quite often.

Mr. Spaulding.—I would say in reply that we have not made any exact tests of its accuracy. Personally I consider the device principally valuable for its range of speed, making the angle such that there may be a considerable difference between the maximum and the minimum radius. The less you make the angle and the less the variation in radius, of course the nearer you approach the flat pulley and the less bad effects you get, as far as precision of operation is concerned.

The Sellers device mentioned above is open to the same defect and belongs to the same class as the wheel-and-disk arrangement mentioned in the paper, since the power is transmitted by frictional contact at what is theoretically one point only, practical results being obtained by the insertion of a yielding surface (as leather), with a resulting waste of energy. The position of driving and driven shafts is also to a certain extent fixed, while in the Gordon device they may bear almost any desired relation to each other.

In the interlocking cone arrangement mentioned, the frictional surface becomes cylindrical only as the number of sections approaches infinity, and the range of speeds is apparently limited.

Arrangements have been made for transmitting power by this method to a portion of the apparatus shown in the Machinery Annex of the Columbian Exposition, and the writer will be pleased to render any desired assistance to members interested in studying it under actual working conditions.

DXXV.*

TOPICAL DISCUSSIONS AND INTERCHANGE OF DATA.

NEW YORK MEETING, 1892.

No. 525—96.

How can the present status of the engineering profession be improved?

Mr. H. F. J. Porter.—That the present time is fitting and opportune, for reasons which I shall try to make apparent, must be my excuse for occupying the attention of the members of this Society just now with a subject which is by no means new. But although it is old I hope to show that it is not necessarily of light importance. The fact that the above question is constantly recurring to our attention is a reason why it should be taken up properly, considered thoroughly, and disposed of in the right manner.

That the present status of the engineering profession is not what could be desired is evident from articles which appear in our scientific press bearing upon that and allied questions. That there is a lack of professional etiquette among its members, such as is observable in the older professions, is brought to our attention by speakers and writers upon the ethics of engineering.

But, let me ask, will the publication of our grievances through the medium of the press change the situation, or is the public the proper body to whom we should address our complaints with the hope of obtaining relief? I think that we ought rather to look to ourselves for the remedy. Rather should we get together and take up the subject for discussion, with the intention of getting at the facts, and making such regulations affecting our interests as the changing requirements of the times may demand.

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* Presented at the New York meeting, November (1892), of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

If we examine the present situation, I do not think that we will find it otherwise than ought to be expected from the circumstances of its development.

Professions are fostered by the manner in which they meet the demands put upon them, but unless their growth is guided by far-seeing minds devoted to their interests, they will split in lines which will cross and interfere with each other, and prevent the normal and perfect development of their various divisions. Now the engineering profession has, from the sudden nature of the demands for development in new directions, been unable to systematize itself, and is not yet old enough to have asserted a system by its own weight. The professions of medicine and law are older and comparatively well in hand. The duties of each member are well defined: they are those of a specialist. Professional etiquette forbids their encroaching on each other's province. The standing of these professions is maintained by the legal requirement of a license or its equivalent before practice is allowed.

Although there have been in all ages men whose qualifications entitled them to be called engineers, our profession, as such, is comparatively young. The steam engine, which has made it what it is, was perfected only a little over a century ago. The term "engineer" was unknown with other than a military signification until the present century. Engineering scarcely ranked as a profession until there were schools to teach it, and there were none such in this or any other English-speaking country prior to 1840. Let us examine its history, and note the sources from which it has drawn its men.

Its development both in this country and abroad has been on similar lines, though in the latter it was at first more rapid. Inventive genius was as quick to mature here, but the country was too new and the amount of available capital too small to foster it. As the country opened up and became more settled, the demand for professional men became apparent. Manufacturing interests sprang into existence, and facilities for transportation became necessary. The first engineering work of note requiring professional skill was the Erie Canal in 1817, and following this came an era of canal building, bringing many able men into prominence, and lasting possibly up to 1840. Railroad building began in 1830, and by 1840 there had developed a strong demand for engineers. Now up to this date there were but two methods of

obtaining preliminary training for the profession; the first by entering as a "student" in an engineer's office or as an "apprentice" in a shop; the other by graduating at the West Point Military Academy. The supply of professional men from the polytechnic schools of France and Germany was not felt, and, with the exception of a few from West Point, the field was filled with men who were self-taught geniuses. The demand for a higher grade of engineer was responded to only in 1840, when the Rensselaer Polytechnic Institute, at Troy, N. Y., opened its doors and began to turn out "civil" engineers. This term had recently been coined to distinguish those engaged in general practice from "military" engineers, whose paths lay in the direction of warfare. For twenty years this school alone supplied technically educated men to the country. Other schools of engineering were founded, yet it was not until 1860 that students began to graduate from the engineering departments of Dartmouth, Union, Harvard, and Yale Colleges, and Michigan University. It is evident that the demand must have far exceeded the supply, and that the ranks were still recruited from the large body of practical men who thus had a motive offered to stimulate their ambition. The technical courses compared with those of the present day were very crude. Experiments had not been made, data had not been collected from which very advanced theory could be drawn. Although the Government lent its aid at last, and the Agricultural College Land Grant bill of July 2, 1862, gave a new incentive to the establishment of institutions of this character, still the war held it in check, and it was not until the country had settled down again that we find technically educated engineers supplied in any great numbers.

During all this time the country had developed with wonderful rapidity. Industries of all kinds were thriving, and competition was creating a demand for men with more of a *mechanical* bent to their training than was given in the civil engineering course. The mineral wealth of the country had become apparent, and the need of men educated in *chemistry and metallurgy* was being felt. The course of instruction in the schools had broadened to comprehend this widening field, but the man who at this time was supposed to be able to solve any and every known engineering problem was a "civil engineer."

But the work was becoming so diverse in character that no one man could devote to it the time necessary to learn it all.

The civil engineering course became too ponderous and broke under its own weight, and between 1866 and 1872 we find a Polytechnic School in Brooklyn and one in Philadelphia, an Institute of Technology at Boston and one at Hoboken, and a department of Cornell University, turning out "mechanical" engineers, while the School of Mines of Columbia and Lafayette Colleges and Lehigh University produced "mining engineers." Still later, when iron and steel began to be supplied for structural purposes, the profession of the architect became merged with that of the engineer, and courses in architecture began to develop; and, still more recently, discoveries in electricity produced schools of electrical engineering.

Thus have the schools followed the growth of the profession and endeavored to supply the demands for the increasing number of specialists. It is evident that schools cannot start their course of instruction in a specialty until the direction and details of its practice have been pretty well developed, and during this time its ranks become filled by pioneers, many of whom rise to eminence, although they may not be technically educated. Even in the older branches there is nothing to prevent the self-taught surveyor or mechanic not only from forging to the front, but from assuming the scholastic title or degree which his neighbor has devoted years to obtain with a considerable expenditure of money.

There are great differences in the methods which the schools themselves adopt for training students to obtain these degrees, and this absence of harmony has hurt the profession not a little. Courses vary in length all the way from three to six years, and the title given at graduation varies to such an extent that it may mean anything or nothing. At one school, before obtaining the degree of C.E., M.E., etc., a man must devote four years to theory, and afterwards a year and a half or two years to practical work; in another, only four years of theory and practice are necessary; while, at still another, three years of theory pure and simple will give the same degree.

What respect can the public have for a profession which is prepared for so variously and which does not attempt to exclude a class of men who may even assert a right to practice on their own assumed qualifications? Regarding these two classes, I have just a word to say, that I may not be misunderstood. Some of the best engineering work of the country has been

accomplished by men who had no technical education as such, and some of the worst has been accomplished by graduates from engineering schools. The result is what we might expect. The title conferred by an engineering school does not inform the public in the slightest degree as to the qualifications of the recipient to perform work. A man makes his reputation in the world by the general characteristics of his make-up and by the opportunities which he seizes. The standing of the profession, however, is affected when its *personnel* is heterogeneous. It is here that the general public loses confidence in us, for it thinks that we should have some jurisdiction over such matters.

There is no standard by which an engineer may be judged. John Smith, M.E., may be a most able theoretical and practical engineer, technically educated, with a most varied and thorough practical experience added; or, on the contrary, he may be a discharged mechanic who cannot hold a position, who has opened an office and placed his name on the door, with the title added on his own responsibility.

There are those who hold that there is a difference between the title "M.E." and the name "mechanical engineer"—that the former is purely and distinctly a degree, conferred by a technical school, and becomes as much part of the name of the holder as his Christian name which was conferred on him at baptism, while the latter may be acquired in various other ways, and should be considered only with reference to the manner of its acquirement.

John Smith, M.E.,

they say, means that the man has at least some technical education; how much is not known; it depends upon the school from which he graduated. As to practical experience, one must ascertain his age and somewhat of his history. But

John Smith,
Mechanical Engineer,

means that he has (or should have) held the position of that title in some shop or similar corporation, and continues to bear it by merit. When a man presents his card introducing himself as

John Smith,
Mechanical Engineer,
X. Y. & Z. Co.,

there is no doubt at all as to his pretensions, provided the X. Y. & Z. Co. is known; but without the limitation where somebody assumes responsibility for giving him the title, there is at present a great uncertainty as to its meaning, and necessarily it is losing its force, and the profession is consequently affected.

It is, however, mostly through the work of the incompetent that the profession is injured. There is no other which assumes as great responsibilities over life and property as does ours. Mammoth office buildings, holding within them an aggregation of thousands of people; ocean steamers of almost as great capacity; railroads of various motive powers, carrying their living freight at terrific rates of speed; dams and dikes which make possible the existence of communities — all threaten frightful disaster and wholesale destruction through the incompetence of either the designer, the superintendent of construction, or the director of maintenance. No other profession can be taxed with such responsibility or claim less careful preparation for assuming it.

Are we not neglecting our duty towards the public by remaining passive in the face of this situation? Are we not assuming the responsibility for this condition of affairs when, understanding it, we make no effort to apply a remedy?

It will be said at once that the proper consideration of a subject of this character is no light task; that it should be participated in by men representing all branches of the profession at a regularly convened congress. It will also seem to be necessary to have a standing committee appointed to prepare the work properly for presentation to such a congress, and afterwards carry out such instructions as might be given by it.

The convening of a congress for this or any purpose is a vast undertaking, and the support of a committee composed of representative members of the different branches of engineering is, under ordinary circumstances, almost impossible to obtain.

The practical impossibility of making the necessary preliminary arrangements might be a plausible excuse for not undertaking such a work.

But just such a congress as this has *already been called* to meet in August next, at the World's Columbian Exposition at Chicago, and a more representative and able committee of

engineers could not have been appointed than *now has in charge* the work of arranging for the details of its sessions.

The Exposition, through its Congress Auxiliary, has already projected the most perfect arrangements for the gathering together of great minds to consider every question which will interest humanity. Not only will the engineer be there, but the educator will be on the same platform, and will be expected to confer with him on questions of mutual interest.

It will be a very long time before such an opportunity as is now presented will again be offered for the consideration of this question in all its aspects.

The committee I have mentioned represents the best engineering societies of all kinds in the United States and Canada. It can formulate this subject and bring it up at the right time.

After the congress has adjourned, the committee, with its strong executive board, could be made perpetual in its nature though changing in its personality. Its duties might be those of a Board of Regents embodied with power to confer titles for merit. Such a board, composed of practical men of the world, would be capable of judging what a man should know in order to bear a title. It should endeavor to bring about a unity of method among the schools as to the education of the engineer, so that a degree given on graduation would mean just what it says, and subsequently, after a term of practice, and after passing an examination, a title could be conferred by the board or its authorized representatives in each State, practically licensing the recipient to practice. Nor would it be necessary to attend a technical school to obtain a title ; the self-taught genius, on proving himself capable, would be awarded one as well.

The task of such a reconstruction and reorganization is a difficult one, but would become less so every year. Boards of Education already meet to discuss such subjects. Pedagogues are reducing their art to a science, and inviting to their symposiums of learning practical men to aid them in the accomplishment of their undertakings

A properly authorized committee has thus within its reach the power to accomplish a work which is far-reaching in its results, and which would fully repay it for its labors.

Let us consider for a moment the present field of engineering.

That it is unevenly divided goes without saying. Originally all was " civil " in contradistinction to " military," but still the

name continues, though the practice has changed, and it follows that this branch is now misnamed. I have in my possession a list of works issued by a well-known publishing house on various branches of engineering. In this list I find books on engineering of the following kinds, many of which are very closely allied. They are railroad, highway, field, sanitary, water-supply, hydraulic, municipal, farm, mechanical, mill, gas, steam, heating and ventilating, mine, bridge, marine, water, naval, maritime. In all of these, mechanical engineering plays a dominant part. Electrical engineering, the latest development, is said to be "engineering, one-eighth of which is electrical and seven-eighths mechanical," and some schools refuse to recognize it as a branch, merely adding electrical instruction to the course in mechanical engineering. It is claimed that in this way a better fitted man is evolved than the graduate of the electrical engineering course, who is more essentially an electrician.

Of late the architect has been drawn rather unwillingly into closer contact with the engineer. The real architect of the present is essentially an engineer, and the number of real architects is rapidly increasing, owing to the influence of the schools. But the man who has a good idea of proportion, combined with a knowledge of history and a fair amount of taste and originality in design, with a quick eye for observation, can, with the services of a contractor and builder, become a very good so-called architect. The existence of these two types of men has done much to prevent architecture from assuming its proper place in engineering. The ordinary architect of the present day holds a very lucrative and respected position, while the engineer who does his work, and for which he gets no credit, is a poorly paid subordinate at the draughting board. It is difficult to determine what field the consulting engineer and the mechanical expert do not cover. It would require more space than I consider to be necessary for the purpose, to dwell upon them here, and they will receive no further comment.

Surely an active committee could not find itself better employed than in establishing a more perfect balance between these different branches of the profession. The tendency of the times is towards specialties, and if the different divisions could be revised in that direction, not only would the preliminary education of each be more perfect and well directed, but the subsequent practice would be more thorough, and the consequent

results more remunerative. If each individual, after his final license is issued, should be compelled to continue in the lines laid down for him there would be no encroachment on the practice of engineers educated in other branches, and professional etiquette among the members of the profession would not be a dead letter, as it is to-day.

For the sake of illustration, let us suppose that students should receive at all engineering schools alike a three years' course in the elements of general engineering, obtaining a degree of Bachelor of Engineering or its equivalent. Subsequently they should be required to perform practical work under the guidance of the school, in lines laid down by the committee, for two years, to fit themselves for examination and license by the committee for one of the special divisions of engineering. They would receive the same education as before, but their standing before the community would be known, and they would fit more perfectly the niche which was cut out for them.

Let us suppose the professional field to be redivided on a more rational basis than the present, so that the student could make his selection more deliberately and prepare for the future with a knowledge of the discriminating scope of his practice. Grouping together similar kinds of work would allow the practitioner to devote himself to a specialty, and he could then successfully cover its literature and keep pace with its development.

The following division is possibly more theoretical than practical, but is offered merely as a suggestion in this direction:

I. Mining Engineering; including the locating, prospecting, and working of mines of all kinds, and, in general, obtaining the raw materials of the trades from the earth.

II. Metallurgical Engineering: the conversion, by the blast furnace, smelting oven, or other similar method, of the raw materials into the finished merchant bar, etc.

III. Manufacturing Engineering: general manufacturing, with a knowledge of international, commercial, and patent law, political economy, methods of obtaining cost of product, making duplicate pieces, etc.; working up the merchant bar into the finished product.

IV. Static Engineering: designing and erection of iron, steel, and stone buildings, light-houses, bridges, ships, etc., with a knowledge of the strength of materials to resist static stresses.

V. Dynamic Engineering: designing and building of generators and prime motors, and assembling them into power plants; machinery and mill work; transmission of power; development of power by steam, air, gas, electricity, and water, with a knowledge of the kinematics of machinery, heating, ventilation, etc.

VI. Land Engineering: laying out and construction of railroads, street railways, highways, laying out of cities, surveying and grading, farm engineering, tunnelling, etc.

VII. Hydraulic Engineering: laying out and construction of canals, docks, dams; laying out of harbors; water-works, sewerage, drainage, fire protection, plumbing, etc.

VIII. Aerial Engineering: aerial navigation by balloons and flying machines; weather bureau, etc.

IX. Military Engineering: fortification, artillery, torpedo service, gunnery, and engineering as applied to warfare.

These lines should be strongly drawn, and the province and duties of the engineer in each division should be well defined. It would not be necessary that a man should practice in only one of these, provided he could obtain a license to direct his work in another. When it became known, however, that a testimonial of proficiency in each of the above directions was required, the public would place more confidence in our work, and would know more readily where orders could be properly placed. The large body of licensed specialists would be able to obtain a living on the standard fees required for their work, and the underpaid engineer would become a being of the past. The incompetent could not thrive, while there would be a good living for all who survived the final test. Regular fees should be agreed upon for specifications, designs, drawings, superintendence, etc., varying according to the type of work considered. Standards should be adopted as to sizes, weights, shapes, gauges, methods of testing, etc. Legislation should be promoted or opposed with the full strength of the profession, accordingly as its interests were to be affected by the proposed measure. As the whole field of labor would be practically in charge of an engineer in one or another of the above divisions, the profession, as the connecting link between the interests of capital and labor, could with judicious management become the arbiter in this most momentous question of the day, and a most important factor in its settlement. These various duties should properly belong to such a standing committee as I have pointed out, and I have little

doubt that many others would also be imposed upon it, although its hands would be full with those enumerated.

That the work here outlined could be accomplished so as to bring about immediate results, I do not claim would be practicable or even possible. Years would elapse before the consummation of such a revision. Yet I do believe that the adoption of some such plan would have a most salutary effect upon the profession in the immediate future, and that when the next Columbian Exposition, like this one made possible by the progress in mechanic arts due to engineering, will compare the standing of the profession then with what it is now, the individual members will see the wisdom of our deliberations in the advanced position which engineering will have then attained.

If I have made it evident that our situation is not what it ought to be, that it has come to where it is from natural causes and from the lack of proper regulation and guidance, my desultory remarks will not have been in vain. I know that if I am right in my premises, there can be no better opportunity than is offered by the approaching congress for devising a remedy and setting in motion the machinery for enforcing it. When there are a known cause for complaint, a known remedy, and a means for its application, I think there can be little doubt that circumstances will bring them together. If my suggestions are too utopian, it will matter little; they are offered to induce discussion simply. I only hope that it is possible to draw from my remarks a cogent reason for the presentation of this topical query at this time, for I have tried to impress upon you that just now there is a tide in our affairs which, taken at its flood, will lead to a consummation devoutly to be wished.

DISCUSSION.

Prof. R. H. Thurston.—If I might be allowed to offer any suggestions, they would be, in brief, these:

1. See that a process of natural and formal selection brings into the profession only those who are fitted for it by nature, and who spontaneously seek it—good mechanics by instinct, good men by original construction, good fellows by nature and habit and training. A man who cannot use a tool, or who cannot see symmetry and proportion in working parts, a man who lacks the constructive talent and the inventive turn of mind, is pretty sure to drop out, once in; but it is better that he should be pre-

vented if possible from entering, and, once in, denied permanent connection with the profession, so far as law and equity permit his repression. His failures and blunders will inevitably depreciate the profession in the estimation of the public as well as of his colleagues. He should be helped out, and, if possible, into something better, precisely as the incompetent student in a professional school is helped out and on to a better place—for him.

2. See that the training of the novice, candidate for entrance into the profession, fits him for at least some one department in which he may be a credit to himself and to his comrades. I would certainly not say that no man should be admitted to the guild who has not a good technical education, for the reason that there are many departments in which success may be attained with a very moderate knowledge of science, pure and applied, and many lines of work in which a good mechanic and natural engineer can do, and does do to-day, the best work known. But this success does, nevertheless, demand qualities of mind and character which impel every such man to make the best and the most of his opportunities; and this will inevitably, to-day, and with the facilities for self-improvement which any such man can command, insure his acquirement of such wisdom and such knowledge as will make him no discreditable colleague of the wisest man and best engineer in the profession. What he lacks in education and scientific attainment, as derived from the schools, he will compensate—often more than compensate—by his practical talent and natural genius, supplemented by the deductions of experience and keen observation. But no man, lacking one or the other—better have both—these special qualifications, can to-day rise to prominence in this profession. Competition with men of education as well as experience, or with men having unquestioned superiority in one or the other line, will inevitably throw the weaker man into the rear. The fortunate and hopeful man to-day is he who has been so happy as to secure a good general education, supplemented by a good professional training, involving the applied sciences, and the systematic training now given in the best schools, in the methods and principles of constructive operations, and who finds himself finally entered upon a practical career, for which both nature and education precisely fit him.

3. The practice of his profession should include such fields of work as will insure that, while the practitioner may gain a good

practical knowledge and reliable experience in the general application of his knowledge and talent, he may certainly become distinguished for accurate and extensive knowledge in some special department. Only the specialist, in these days, can be sure to meet satisfactorily the constantly increasing exactions of professional work in any given line. He must, to succeed, "know something about all things, all about something," professionally, to such extent as talent and opportunity may permit—and he must make his talent find his opportunities.

4. The ideal education and preparation for the young engineer, as I should outline it, would include, first, just as good a general education, just as "liberal" an education, as can be afforded, and as time will permit. As President Gates remarked, the other day, in his inaugural at Amherst, and as other wise men have said before him, "It is better that a man should be successful in his profession at thirty, than that he should enter it at twenty," and the highest success is attained when a man is well educated, as well as professionally well trained. This education must usually, and perhaps necessarily, precede the professional training, and we have each year a larger number of young men coming to take up the professional courses in the technical schools, after completing their "liberal" and general education, and at from twenty to twenty-two or three years of age. I have no doubt that, in some cases, this means some sacrifice of aptitude for the profession, and some loss by ingraining the man with the scholarly, rather than the practical habit; but every one must decide for himself just how far he can or should pursue such a course. I am myself inclined to think that, if the man has the genius of a Watt, or a Corliss, or an Edison, or a Holley in him, the best education in the world could not extinguish it. It certainly did not in the case of Holley. If this be so, I should say that the man who looks beyond professional success and the acquirement of a competence, will be inclined to fit himself for the making of the most of life in the broadest sense possible, and in the best possible manner, and would insure that preparation which only a broad education and real culture can give.

The professional training should, in my opinion, include a very complete scientific education, supplemented by a very carefully adjusted course in applied sciences, finding application in

his professional work, and in all the purely scientific and mathematical operations in daily or frequent use in professional practice. The scientific methods of exact measurement, and those of experimental investigation, are coming to be the leading and most essential departments of instruction in the schools, and constitute, in the best of such schools, as regular and as essential exercises as the more elementary work which has hitherto been thought, by many, the final work of the professional course. Mechanical as well as physical or chemical laboratory work now constitutes, in many cases, one of the essential courses of instruction, and runs through the later years of such schools with as much time devoted to it, and with as careful assignment and as nice development of method, as in either of the other laboratories, or in any other department. Some of the finest work reported in our *transactions* comes of the application of all the resources of such laboratories, with their trained observers and remarkable collections of apparatus, to such purposes.

But schooling, even professional training in professional schools, has little value unless supplemented in turn by a varied and fruitful experience and a special line of practice. The best-educated graduate of the best school in the country—if there be a best—has less value for much of his professional work than the unschooled mechanic beside whom he must often work, and with whom he must often compare practical working power. If a good man, however, the trained powers of the practically educated student soon exhibit their superiority, and the educated practical man combines all the elements of professional success, so far as preparation can give them.

5. *Character*, after all, however, is the final touchstone by which the profession, like its individual members, will be judged. These matters of education and of training will certainly, in time, take good care of themselves. We may trust men not to enter a profession so exacting, without the requisite preparation for its work; and ambition will lead the strongest men to make the most and the best of their opportunities and of their talents. The extraordinarily severe training now demanded of its members will insure that respect, other things equal, which is accorded to the older professions, and in time, I think, *even higher*; for no profession is to-day so exacting of its training schools, as is that of engineering in all its depart-

ments. The advancement of the last twenty or thirty years has, in this respect, been wonderful, and may be expected to continue just as long as our professional schools and our professional practitioners are able to hold up and to advance the standards of schools and profession alike. The profession will be judged by its work and its men, and will advance or retrograde accordingly. Good men without ability, and bad men with ability, will equally, and in the end, inevitably, fail, and will lower our standing; but good men doing good work will elevate it, always and permanently. Good education, good professional training, a high standard of work in schools and in practice alike, a well-established and well-sustained professional *ethic*, such as honest men and honorable men and men of good interior character can subscribe to and uphold, and an honest man's pride in his work and in his vocation will make and preserve a status with which we shall all be entirely satisfied, and of which we shall have reason to be proud.

I think we have reason for neither apprehension nor mortification in the standing of our profession to-day. No modern instance of such rapid progress as we have made since the institution of schools of engineering can be found among the professions or among the vocations. A generation ago there was no profession recognized as engineering. To-day, it is not only recognized, but its members stand among the learned and the great of the older professions without disparagement. I think we may trust the schools and colleges of the country to supply as good education and culture as its members can either wish or ask; the professional schools will give all that the students can take of professional training, and practice will offer them all the opportunities that they are equal to. Their standing in the community may be trusted to take care of itself, if every member adds his mite to its credit.

No man, or body of men, has the right to say who shall enter the profession; the public will see that the right men leave it; the schools will, in good time, find ways of placing the right mark on their men—if it must be assumed that any other mark than that of competence to identify themselves by their work is needed—and the profession, as a body, has for its special work in the good cause the sustaining of high ideals, and of good work among its members, and correct relations with the people at large. We shall have excellent reason to be well satisfied

and proud of our profession, if we can continue to point to as rapid advances in the immediate future as we have seen in the one of two decades just past.

Mr. John T. Hawkins.—Having read Mr. H. F. J. Porter's very able discussion of this wide and important question with great satisfaction, I am prepared to indorse him throughout, so far as he goes. I believe that something like the course he recommends is at this time most desirable. The question is, however, of such breadth that no one of us can hope to do more than point out some particular direction, or directions, in which improvement may be looked for or made, as likely to be useful to any committee or convention which may undertake its general solution.

If I can in this way assist, in however small degree, in a needed improvement in the status of the profession, I shall be glad; and to this end desire to revert briefly to an aspect of the question, to the discussion of which I have contributed in past sessions of this society, and elsewhere.

I cannot better place the idea I desire to advance, or in more definite shape, perhaps, than as follows: the profession of engineering, necessarily divided up, as it is to-day, into the many branches pointed out by Mr. Porter, either as covering one or more of these branches, or regarding the profession as a whole, is in reality again more sharply divided into two quite distinct kinds of engineering and engineers. I may properly, I think, to convey my idea, characterize these as the hypothetical and the creative. They are, perhaps, equally important in the engineering world, but in any well-settled movement looking to the improvement of the status of the engineer, this distinction should have greater recognition than it now obtains.

In the early days of the profession, as Mr. Porter well says, the work became "so diverse in character that no one man could devote to it the time necessary to learn it all;" referring to the then only known variety of the species, the "civil engineer." The differentiation of the engineer has since gone on until we now have, as pointed out by Mr. Porter, some nineteen or twenty pretty well recognized divisions of the profession. This differentiation has been brought about in the natural evolution of the engineer as controlled by his environment; not always resulting in the survival of the fittest. There is, however, one other, and a more decidedly marked division

than any of which he makes mention, and that is what I have above endeavored to convey in the terms hypothetical and creative.

By hypothetical engineers I would be understood as meaning such men as Clausius, Regnault, Carnot, Rankine, Professor Wood, Dr. Thurston, and many others who fill and have filled a place in the profession, whose luster it would be quite impossible to obscure had any one a desire so to do. Without such as these the profession would be to-day groping in cimmerian darkness so far as most of the fundamental questions are concerned, which lie at its foundation.

The other very distinct class is typified in such men as Watt, Whitney, McCormick, Ericsson, Hoe, Corliss, Leavitt, Edison. Such men constitute the creative, in contradistinction to the hypothetical engineers. Nothing invidious need be entertained as to either. Both fill a most important and indispensable, and, perhaps, a not unequal place in the development of the engineering world.

Now, the point I desire to make is that the educational preparation of the engineer is to-day too largely leaning toward the development of the hypothetical rather than the creative engineer; or, at best, attempting to produce what, in view of the vast field to be covered, too often proves to be an ineffective combination of the two.

It would not be too much to say, perhaps, that not one of the eminent men last-mentioned have ever had any available knowledge of the transcendental analysis, or would have used it if they had, without which, in entire completeness, the first-named nestors of the profession would be as helpless as racehorses without legs; and it would be quite as well within bounds to say that the refinements of analytical study, if imposed upon the men I have named as creative engineers, would be no other than a Sindbad's load, and a waste of the time they had been called upon to devote to them, either in their youth or at a later day.

The fact is that the great mass of what I have indicated as creative engineering work, in either or all of the recognized branches, can be well procured through engineers not in possession of the slightest knowledge of the calculus and its companion, analytical geometry. For such an engineer to be well grounded in algebra, geometry, and trigonometry—which are as intimately companion studies as are the more analytical pair

first mentioned—if we add descriptive geometry, is as far as he can profitably go in the direction of the pure mathematics.

As Mr. Porter says: "Some of the best engineering work of the country has been accomplished by men who had no technical education as such, and some of the worst has been accomplished by graduates from engineering schools;" and no fact adduced points more strongly to the necessity for some such division of educational preparation as I have attempted to point out. If the former are capable of producing some of the best of engineering work without technical training at all, how much more efficient may we not suppose they would have been if they had been favored with such a training as could be devoted to and directed toward the development of just the kind of an engineer which nature had primarily fitted them to become, instead of indiscriminately directing their preparation, to make of them partly hypothetical and partly creative engineers, with great danger of spoiling both? This is visible enough to-day in the too many instances of so-called engineers who are neither the one nor the other, to any degree advantageous either to themselves or to that part of the world which needs the services of an engineer, hypothetical or creative.

There is a disposition, I imagine, in the profession to regard the engineer who is without a knowledge of the higher mathematics as occupying something of a lower status as such; and it is not to be doubted that, as these matters are now ordered, many young men would regard themselves in a manner disrated—to use a naval term—if graduated from an engineering school without having spent sufficient of his college time to be able to apply and use the transcendental analysis in engineering problems, or at least to play with it when he felt like it. This is a mistaken idea, however. The true measure of the engineer, as of any other professional man, is the performance of correct and competent work in the branch he may elect to follow—and in these days we must make an election.

If his desire is, and he feels himself fitted, to become what I have designated as an hypothetical engineer, let him direct his course that way; and if he succeeds as well in it the world will accord him all the honor that it now renders to a Rankine. If he feels himself better endowed by nature to master the more creative factors of engineering, the world will honor him no less if equally successful in his sphere; while, generally, he may look

for a better pecuniary reward than is achieved by those others, whom most of us may, perhaps in a thankful spirit, regard as in great degree pecuniary martyrs to their profession.

No man who has a natural and healthy appetite for knowledge, if graduated from an engineering college, as I have suggested, without training in analytical mathematics, could be likely to go through an engineering lifetime without improving his mind to some extent in that direction; and every creative engineer is better equipped, moderately late in life, to easily acquire something of this than in his school-days, when so much of other more indispensable studies are crowded upon him.

If I were possessed of superabundant means, and a desire to gratuitously devote some of it to the advancement of the profession of engineering, I think I could confer no greater benefit than by endowing, in every engineering school or college in the land, what, for want of a better title at this time, I will call a chair of invention—giving it some more dignified title, if advisable—then pick out a lot of fairly well educated mechanical schemers, not better employed, to fill them. The country is full of such, and there would be no trouble in getting all that was needed. Of course, they would have to be moderately well paid, for this sort of man generally succeeds in paying himself pretty well. I would reserve this branch of study and training as more particularly to be devoted to men best equipped naturally for creative engineers, and give them little or nothing of the higher mathematics.

A great deal has been said and written on the value of analytical study as a school of the mind; as enlarging and developing the reasoning faculties; but, while this is true in a very general sense, no doubt, I do not believe that it is of much avail in the peculiar kind of reasoning power demanded of what I have tried to distinguish under the name creative engineer—or the inventive engineer, if you will. Rather do I believe that any considerable indulgence in that sort of thing tends to unfit that sort of man, in a measure, to become what, with less of it, would result in a capable and efficient constructive, inventive, creative engineer.

It has been objected that an engineer not well up in analytics labors under a great disadvantage in being unable to read and interpret much of the best and most profound of engineering literature; that such works are practically sealed books to him.

While this objection has some cogency, it is to be remembered that—unlike the figures of the politician—those of the mathematician do not lie. Engineering writers always give us their conclusions, and we may not forget that while unable to verify the work of the hypothetical engineer in his writings, we may with confidence accept his conclusions, arrived at, as they are, through mathematical demonstration. We can feel sure of our ground, whether or not we comprehend the processes through which the solution of a problem is thus found.

All this is very crude, no doubt, but if the outcome of this discussion is that some sort of commission or convention is instituted for the general resolution of the far-reaching problem given in this topical query, I hope the views I have here advanced may be of some utility in aid of the unfortunates who may be delegated to take the matter in hand.

Mr. John H. Cooper.—In whatever way engineering can be aided, it will ever be true that records of good work should be put in the channels of technical literature, in order that knowledge often exceptionally conceived and dearly won shall not perish, but live to help those who follow after.

During the time of my collecting data for belting I made the acquaintance of an engineer whose life had been devoted chiefly to the practical side of our profession. I asked him to give me the results of his experience for publication, in the line I was seeking for information; his reply was: "What I have obtained was hard earned, during forty years, and I want it for my own use." Years afterwards I wrote to find his whereabouts, with a view to opening correspondence again; my respondent replied: "Not able to give his present address, he died a year ago"

So now, while we have your present address, cannot each and all add something to present knowledge, before the gems of thought which you possess go into the never, and become lost to every one of us? There are many in membership with us who have solved important engineering problems, and who, perhaps, will not be called again to them in a commercial way; would not the rising engineer be benefited by access to well-illustrated, full records of these upon the pages of our *Transactions?*

I have even found that a study of patent-office reports will give an important, as well as a less known, side of engineering history, not to be found in our text or professional books. To

test this erratic statement, get all the patents in any one class, and you will be surprised at the multitude of offers in the shape of mechanical elements and data for the accomplishment of some particular object.

How much better to have the solid history of work actually done and faithfully reported in our *Transactions*, than to tread the uncertain ground of mere proposals to do something.

It would be as throwing words away to say here how individual effort may be made to bring about best results. Franklin tells us, "The noblest question in the world is, what good may I do in it?" He may not have meant engineering good, but we will accept his words as so applying, since his mind was very bright in practical, as well as comprehensive in economic, science.

You will hardly forgive me a bit of plagiarism from Socrates, who said: "Let him that would move the world, move first himself." Why, certainly; he must go and get the Archimedean lever and the "where to stand," before he can move the earth. So our stamp shows it.

Inscribed upon an ancient crest of a pickaxe are these trenchant words: "*Either I will find a way or make one.*" A good motto for an engineer, but his work is not done till he publishes how he did it.

Mr. George Hill.—I feel a diffidence in following after gentlemen of much experience and learning, with very few notes, but I feel that the purpose of the Society is primarily to exchange views on subjects of mutual interest, and in this light offer what follows:

As stated in the official programme, this subject has a dual aspect; first, the improvement of the status of the engineering profession; and, second, the question as to overhauling the right to use the name. Since we can improve our status without taking up the second question at all, we can discuss Mr. Porter's paper, which bears particularly on the first point, and incidentally treat the second.

The improvement of the status of the engineer is a subject which is of great importance, not only to every member of the profession, but to the community at large also, and to a greater extent, since the results of poor engineering entail on the community a constant overcharge for maintenance which is ever swelling the capital account, or necessitating an enhanced charge

against the depreciation account; while the effect on the engineers is to make the fees less on the part of the good practicians, while the effect on the blunderers is not apparent until a long series of blunders has been consummated.

The only way to begin the cure of any disease is properly to diagnose it, after which the application of the proper remedy is only a matter of trial or experience, and to this phase of the question we should first bend our attention.

Mr. Porter gives prominence to the statement that there is a lack of professional etiquette among the members, which is in striking contrast to the practice of the members of the older professions. This is again referred to; and the paragraph in the middle of page 488 gives rise to the question, What are our grievances? Are they real and radical? or are they simply the exemplification of the contrariety of human affairs?

We would gather that as compared with law and medicine we receive less consideration and are subject to business conditions of competition; one of which hurts our vanity and the other our pocket. It is said that if we could only have a lot of laws, governing bodies, etc., we would be better off.

Let us look for a moment at the professions of medicine and the law, to see if this is really the case. In each there is a body, similar to that proposed in the paper we are discussing, that after an examination issues licenses to practice. This is no doubt a good thing, but it certainly will not be maintained that by reason of this license all of the incompetent doctors and lawyers are weeded out and the profession improved; indeed, the average man knows of plenty of ignoramuses who are as injurious to their profession as any man could well be.

Nor does professional etiquette hinder the members of these professions from doing many a stupid thing, or worse, and if the man possess ability of a certain kind, it does not hinder him from advertisement of the most glaring kind to the benefit of his pocket. Neither does the fact that a man receives his diploma or license from any particular source give him any particular prestige, and is only beneficial in so far as it requires a more perfect understanding of the subject, or puts a man in the way of enlarging his acquaintance.

A further examination of these professions will show that while they are highly specialized in the practice of the most prominent members, yet practically all of these specialists

reached their present position through the drudgery of a general practice, and the majority of the members are only good general men, doing good and living lives which are an honor to their calling, but still general practitioners.

What has given prestige to the "three learned professions" is the fact that they are *learned*, that their practice required that the men who devoted themselves to them were of necessity forced to mingle with their fellows and so cultivate an "esprit-de-corps" which led them to respect one another, thus leading up to a code of etiquette which compelled all who desired to be considered of the better grades to comply with it.

The general dissemination of knowledge with which we are familiar is a matter of comparatively recent growth, and formerly the possessors of this knowledge formed but a small part of the community, and were men above the average, were much respected, and doubtless we still are somewhat influenced by this feeling. If we command the respect of our associates, we have all that we can desire in the way of an amelioration of our position, since this is a condition of affairs which spreads rapidly. Take even the presumed state of affairs spoken of in the closing paragraph of page 494.

Those architects who really occupy a leading position in the profession, and they are more artistic than practical in the bent of their mind, treat the man who does the practical part of their work in a way that leaves little to be desired. Speaking from a personal experience of nearly three years I can say that, far from being the poorly paid subordinate that Mr. Porter speaks of, the engineer "who does his work" receives all of the credit to which he is entitled, and is usually rated as equal in importance to the artistic and business man.

If the trouble is taken to read my article on "The Management of an Architect's Office," in the *American Architect*, No. 816 *et seq.*, this will be fully shown.

Considering the divisions as given on pages 495 and 496, the engineer who works with the architect would need to have licenses in at least four branches, a condition impossible of fulfillment if more than a good general knowledge were required.

If the lines of demarkation were strictly enforced it would entail useless hardship on the profession of architect and unnecessary complication to the client. To illustrate further,

it is required that there shall be a good designer, a good business man, and a good general engineer in each office. Now, it is impossible that one man can be all three. If the division as suggested were carried out there would be required six men in each office—a state of affairs which would force almost all of the work into the hands of half a dozen men. The better practice is to have two or at the most three men, at the head, and then, for works of importance, call in the expert in the particular branch under consideration, who can suggest improvements which can be carried out when they do not conflict with other requirements of greater importance.

The practical working of the large body of licensed specialists would probably result in the necessity of a special court to decide on the relative importance of the various branches in each case, so as to combine them into a harmonious whole, practically perfect in general, though not in all details, since perfect work in every branch is always impossible.

Our trouble lies in the fact that in the present age of enlightenment we do not receive the same consideration that the learned doctor or lawyer does, and we think we should have it. Our dictum in matters within our province is not received as final, and we are constantly being harassed by the competition of our needy brothers, who, to live, are willing to take less than we think is right.

We are right, beyond any question, in feeling that we are the equals of the doctor or lawyer, for if we could but have our way we would make the world so healthy that the doctors would be unnecessary, and the people would be so generally prosperous and happy that the lawyers would starve to death.

Now, suppose we should undertake to overhaul the right to use the title, what good purpose would it serve? No amount of legislation can prevent a man from doctoring himself if he wishes, nor can the folly of the client prevent some men from being their own lawyers; and we would find the same trouble in keeping men from being their own engineers, or acting on the advice of their friends if they wanted to.

The most of the people are not yet sufficiently educated to have determined approximately the limits of their knowledge, and will therefore resent any attempt to compel them to acknowledge their ignorance. We can only reach them through the influence of superior knowledge, affecting ever a wider circle.

Let us address ourselves soberly to the task. First, let us raise the standard of admission to our Society until it becomes necessary for a man to have been tried in the fires of practical experience and have proven his worth before he can attain to full membership.

Second, make some grade intermediate between junior and full member that men may occupy who are too old to be juniors, but have been unable from force of circumstances to acquire the experience necessary for full membership, or whose work, while affiliated, is still not such as to entitle them to be considered as professionals.

Third, let every man who is connected with the Society be ever on the alert to do it a good turn; attending the meetings, participating in the discussions, advising his assistants to join, and helping them with advice or money if necessary.

In the future a large majority of engineers will be graduates of our technical schools, and they will make the status of the profession for good or ill.

The faculties already are recognizing the necessity of having the students brought into contact with the men who are in the actual practice of their profession; they would do well to follow in the footsteps of one of our number who chose, as the subject of his address to the graduating class of one of our institutions, the "Moral Obligations of the Engineer," and instruct the student in this branch also. From such a course a code of ethics will come in good time, is coming now in fact, but it will do no good unless *we* respect it ourselves.

Finally, let us respect ourselves; leading sober, earnest lives, doing all that we can to better the condition of every one with whom we come in contact, and following generations will attain the desired goal.

Mr. W. Barnet Le Van.—There is one point upon which none of the speakers have touched. To be a good engineer requires good judgment, and that is the whole secret of it. One of the best engineers in the country, who also is a member of the Society, and whose talent and good judgment have put him at the top of his profession, was nothing but a country blacksmith originally, with a limited education.

Mr. T. W. M. Draper.—I am very glad, indeed, to see this subject discussed at so much length. I propose another solution of the subject which has not been touched upon. It is especially

the fault in America that our technical schools are not practical enough. Now every college man, when he comes into practical life—I had the experience myself—finds very often that the foreman over whom he is placed knows a great deal more about his profession in a great many instances than he does himself. To illustrate, I will merely take the case of Columbia College—the School of Mines Department—here in New York. There is not a mine in New York. There is no place where a young man in the Columbia School of Mines can obtain practical work in his chosen profession before he graduates, unless he goes away from the city on long and expensive journeys, or takes his summer holidays for that purpose. They understand that a little better abroad, where they combine the practical work with the theoretical. Now I have very often found that this question comes up in practical life. It is coming up more every day—this question as to who an engineer is, and who is not an engineer. I think the "mountain began to labor" about two years ago, and I hope it will bring out something very big, especially next August. We are all interested in the question because we all have seen how incompetent men have prevented good men from obtaining their just share of work, by the cutting of prices for it. I do not think that any rule that can be laid down by Congress, however, will check this evil so much or so well as the men in the profession to-day can check it themselves, by their example; and I believe that the best solution after all will come eventually, first through our technical schools, and, secondly, through our technical societies. The higher they raise their grades the higher will they raise the grade of the engineer. The true solution will come with the raising of the grade in our technical schools, with the combining not only of theory and practice but of business knowledge; and in our societies, raising the grade of the societies—not making too many classes. There is not an engineering association in the United States which would not be proud of the membership of Mr. Edison, yet Mr. Edison is not a college graduate. No one would ask him to enter as a junior or in an intermediate grade. He would undoubtedly be elected to this Society, or any technical society, as a full member. Take a man on his record, on his past, on his experience, on his practical life. When I first came into practical life I found that I had a great deal of

the theory of my college life to forget before I could be of any use to any one. I think this solution has not been touched upon. It has been discussed in many ways in our engineering magazines and papers, and I have done my little share in that direction, as many of us have. We are all anxious to see it solved, and time will solve it; and I believe through the raising of the standard, through colleges, and through societies.

Mr. Oberlin Smith.—I am heartily in accord with the substance of this paper, and I feel most earnestly that there should be a higher standard for our profession, a more definite knowledge as to who is who. I will not stop now to go into the details of classification, or anything of that kind. My views upon this question appeared some months ago in the *Engineering Magazine*, and allusion was there made to the misnomer "civil engineer" —as applied to one only of the non-military branches of the profession. The point I want to speak of now particularly is this: Not only should we have a definite name for the profession of *Engineer*, standing by itself for general purposes, with such adjectives as may be appropriate for the different branches, but we should have some kind of a monopoly of that name, or else we should have some other name entirely. Every man who can run a farm-engine out on the prairie, burning straw or corn-cobs, and who knows enough to open and shut the fire-door and turn the valves, is an "engineer"; it doesn't make any difference whether he can read or write—he is, all the same, an engineer. I see in a to-day's paper, which I happen to have in my hand, the first column headed, in big lines, "Brotherhood of Locomotive Engineers," and another more modest column headed "Mechanical Engineers." I know a great many people have a hazy idea of what an engineer is. They think he is a man on a locomotive with blue overalls, or they think he is a man in the stoke-hold of a steamer shovelling coal. When they see the American Society of Mechanical Engineers mentioned, they think it means something of the same sort—perhaps some kind of a trades union. It is only in professional circles that a clear idea exists of what an engineer is. Just what is the best practical way of dealing with this difficulty is not easy to decide. I think we ought to keep the title, because there were engineers in the world long before there were steam-engines, and the greaser and the farm-engine man have taken the name since these steam-engines have been gotten up. I notice there is a

tendency in some of our technical papers to speak of the man on the locomotive as the "engineman," and in England "engine driver" is used. Should we not, in all the technical societies, join in some effort to start a reform—perhaps by appointment of committees who would confer with one another? Perhaps something could be done at the Chicago Congress to induce the public to make a distinction. If by such joint action we can persuade all the technical journals habitually to use the term engineman; if we can influence some of the great railroad companies to use that word officially; if we can induce the steamboat companies to do the same thing, we might very soon make the change. Last, but not least, we want the coöperation of our college faculties, who would be very apt to favor the change. The larger city newspapers can also be influenced, and this other word "engineman" (or a good substitute) would gradually be adopted, for designating the man who simply drives the machine which engineers have designed and built. I do not know whether we can do anything at this meeting in the way of committees or anything of the kind, but it is something we all ought to think about, whether there cannot be a reform in this important matter. I do not say all this with any disrespect for the man who wears a blue drilling jacket and drives an engine; many of them are very bright men and become truly engineers in time. It is, however, only fair that until they are educated up to the standard of professional men, they should have some name of their own, and not ours.

Mr. W. F. Durfee.—I wish to point out one view of this subject which has not yet been noticed, and I will endeavor to do this very briefly, as the discussion is somewhat prolonged already. It is this: So long as we receive men into this Society by the vote of its Council and members, we practically confer upon those men the title of Engineer; and as long as that practice continues I do not see but that we are bound to abide by its results. The Society should be more careful than in very many instances it has hitherto been, in conferring that title. I am reminded in this connection of a circumstance which is said to have occurred soon after the Pilgrims, amid the snows of December, landed upon Plymouth rock. We are told that they had some qualms of conscience as to whether it was exactly just to take the lands of the Indians without compensation. They had a convention or "caucus," and prayerfully considered the situa-

tion, and arrived at this conclusion: First, "The earth is the Lord's, and the fulness thereof." Second, the earth was given to "the saints." Third, *we* are "the saints." So long as we practically confer the degree of Mechanical Engineer by admitting men to our Society, we have got to be content with asserting that we are the saints, and accept the responsibility of whatever carelessness we have been guilty of.

Mr. H. C. Spaulding.—Before dropping the subject, I should like to say a few words which may properly come from one of the younger members of the Society. There is a criticism very often heard, and I think with considerable justice, upon graduates of technical schools, to the effect that they "know it all" and want to start in at the top instead of going in at the bottom. Is this not partially due to the fact that the young graduate feels himself entitled by common consent to assume the title of "engineer" in a certain department of engineering, which is exactly the same as that borne by men many years his seniors, who have grown gray in meeting the problems which he as yet knows nothing about from the practical point of view? It seems to me as though that state of things could be obviated considerably by having some title or name toward which he could work, but which he could not assume until considerable practical experience had been acquired. Now, carrying on what has been said, that "we are the saints," why not make the standard of admission much higher, so that new members, instead of being simply engineers, would be recognized as "Members of the American Society of Mechanical Engineers"?

Mr. William Kent.—Before speaking direct to the paper, I would say a word with reference to the remark made by Mr. Draper, that "the technical schools are not practical enough." As one who graduated in a technical school myself, in the class of 1876, and being now connected with one in an official capacity, and having made a study and comparison of the methods of other technical schools for the last fifteen years, I would say that the technical schools of this country are practical enough. It is now found by the faculties of technical schools that the four years' course is scarcely long enough to ground the students thoroughly in the principles on which engineering is based, and some are clamoring for a five years' course instead of four. All of the technical schools now give a partial practical course. If they were to devote more of the time of the students to practical

work, which they are bound to get in future life, to the subtraction of the time they give to mathematics and the principles of engineering, they would, in my opinion, be taking a retrograde step. You cannot teach both the necessary amount of theory and a desirable amount of practice in the limited course of four years. When the student graduates and goes into practical life it is very hard for him afterward to acquire the theory, but he is bound to get the practice. I know some graduates of technical schools whose first job after they graduated was that of apprentice in some machine shop or rolling mill at a dollar a day. I know of three such men in my own class, and they are now at the top of their respective branches. Two are superintendents of motive power of two of the largest railroads in the country, and the other is superintendent of a large steel works. I had the privilege a few years ago of lecturing, at Professor Hutton's request, to the senior class at Columbia College on iron and steel manufacture. One of the young men about to graduate told me he had an opportunity to go into an open-hearth steel works, and asked me what department he should go into, stating that he thought the draughting room would be a good place to start. I said, if you can get into that department where you can go down into the pit and daub the ladle, it will be better for you in the long run. That practical experience of daubing the ladle, of watching a heat, cannot be taught in a school. It must be taught in practice outside.

Now as to the points in the paper: It is said twice in the paper, once on page 489 and once on page 495, that there is a lack of professional etiquette among engineers. I do not think that charge against ourselves is well founded. I think there is no greater lack of professional etiquette among the engineers of the country than there is among lawyers and doctors.

As to a division of engineers into the several classes recommended in the paper, the author says if each individual, after his final license is issued, should be compelled to continue in the lines laid down for him there would be no encroachment on the practice of engineers educated in other branches. Now, Mr. Hill has spoken to-night of the number of different kinds of engineers required for an architect's office. To go back to iron manufacture, let us ask how many different kinds of engineers are needed to build and manage an iron works. He has first to be a mining engineer. He has to be a metallurgist, to

know how to smelt the ore. He has to be a manufacturing engineer, that is the third class in the paper, with a knowledge of commercial and patent law, methods of obtaining cost, making duplicate pieces, etc. He has to be a static engineer, the fourth class, to erect iron and steel buildings. He has to be a dynamic engineer, the fifth class, to design and build generators and prime motors and assemble them into plants. He has to be a land engineer, the sixth class, in the construction of railroads, at least from the ore beds to his works. He has to be a hydraulic engineer in designing and building his pumping plant. I do not think he has to be an aerial engineer, the eighth class, (a friend at my side, however, says the aerial engineer is needed to "float" the company, and also when it "goes up in a balloon"), but recent practice at Homestead shows that he must be some thing of a military engineer, the ninth class. The iron works engineer is, therefore, all kinds of an engineer at once. He must "encroach" on all branches. This instance, and that of the architect's office, I think, show that the proposed division of the profession into distinct branches, and the compelling of any one "to continue in the lines laid down for him," will be found impracticable. For a direct answer to the author's question, "How can the status of the engineering profession be improved?" I would say, "By evolution." If there is as much improvement in the next ten years as there has been in the last ten we should be entirely satisfied.

Mr. George S. Strong.—I recall a number of instances of having discussed this subject with prominent engineers in different parts of the country and in Europe. A few years ago I was in Vienna. I met Mr. Carl Pfaff, who is one of the principal mechanical and civil engineers of Austria, and a man who has taken a very lively interest in American affairs. He told me that he had been very much interested in the rapid development of engineering in this country, and had been surprised that we had accomplished so much with so few technical colleges. He said: "You seem to jump to the bottom of every subject; we put our young men through six and seven years of technical training, and when they are through they are so full of book knowledge that you cannot cram anything else into their heads." That leads to a practical question which has come up in every engineering office and every large establishment in the country, and that is this of having a young man come out of college with

a willingness to do as my friend on the right has suggested, and that is, commence at the bottom and go to the top. A few years ago one of them wrote to Mr. Forney, who was then the editor of the *Railroad Gazette*, and said: "I am a graduate with high honors at one of our principal technical colleges. I want to become a practical railroad man. Where shall I commence?"

Mr. Forney took him rather unawares by saying: "I would take the presidency, if I could get it; if not, I would take the treasurership." About six months ago I was in a large steel works and the manager said: "I am bothered to death with the applications that I am having from these different colleges to allow the young men to come in and spend their vacations in the establishment." He said: "I have generally refused, but I have made one concession on the application of one of the professors to let a young man who, he said, was very bright, spend his vacation in the establishment. He was willing to do anything, he said. I told him I would allow him to spend his vacation with us, provided he would work as an ordinary workman in one department. I would let him stay there long enough to get familiar with that, and then I would transfer him to another. He spent one week in the bridge department and then he wrote to the general manager that he had been there one week and knew all about that business, and wanted to be transferred to the machine shop. That is the trouble I find with young men. I do not disparage technical education. I think every young man is benefited by having it if he is willing to use it as it should be used, and I myself prefer to employ educated men, but I find that I cannot get that kind of men to commence to work as young men are very often willing to work who have not got those advantages." Now, as regards the question of the man with the overalls that my friend on the left has spoken of. I know a number of locomotive drivers in this country to-day who are better mechanical engineers than one-half the men who are practising.

Many of these men have risen to high positions in the practical work of engineering; one whom this Society honored the other day by rising to receive him in session, commenced his life as a locomotive engineer, and is not ashamed of it, and many who are worthy of being members of this Society by reason of the ability they have shown in the solution of practical questions of engineering are still driving the iron horse. One whom I have the pleasure of knowing, who has shown his

ability as the designer and inventor of a balanced valve for locomotives which is largely used, and which has brought him a considerable income, which would enable him to retire from the work to which he has devoted his life, still drives his locomotive on the same express which he has handled for twenty years, and feels that no other life would satisfy the tension to which his nerves have become accustomed. But to ride with him and see the degree of refinement to which he has reduced locomotive running, cannot but excite admiration, and one does not wonder that there is a fascination about it that retains men of the highest abilities, so that it has become a saying, "Once an engineer, always an engineer."

As to the question, Who shall use the title of Mechanical Engineer? I would say, he who is worthy, whether he be college graduate or one who has risen from the ranks, and we cannot but heed that divine injunction, "Ye shall know him by his works."

Mr. Robert Cartwright.—I am not a college graduate. In Mr. Kent's remarks I heartily concur. I do not decry technical education. Thank God, we have it. But you can't make a square pin fit a round hole. There are many poor engineers who have been started out, and good shoemakers have been lost, as a result. All the diplomas you may grant will not make an engineer. Judge him by his work, not by the parchment. I have been forty-five years actively employed in engineering. I won't say what branch, because I have had a little touch of everything. I have driven a locomotive, leaving $1,000 a year to take $60 a month, to drive a locomotive for the experience of it. I studied engineering when I was serving my four and a half years' apprenticeship at marine engine building for $2 a week. I did not get the dollar Mr. Kent talked of, and I wish I had had the opportunity of the education. But your colleges will never make an engineer. By your work you will be judged entirely. Within the last two weeks an engineer came to me and said, "Mr. Cartwright, can't you move your wheels up 600 feet, and then you won't need to have that long 600 feet of shafting to drive?" I said, "Yes, but I have spent $75,000 to put them where they are." He said, "I want to run a sewer where you have got your wheels. Now, can't you move your wheels up to the next street? Can't you move your wheels up and let me run my sewer?" I said, "Very nicely. What shall I do with the

water?" He said, "Oh, turn it back to the river again." He was a college graduate. I said, "Where shall I get my power from?" He said, "I never studied hydraulic engineering." Nobody can honor technical colleges more than myself. Nobody is willing to do more for the younger generation than I. I do not want to hide my light, if I have any, under a bushel. Engineers are created by God almighty and not by technical colleges.

I am glad to see this subject brought up, because I think, six or eight months ago, I opened this question in this very house. I said then: "What are you doing in your technical colleges? You are educating officers who are ignorant of the duties of the men they have got to handle." At West Point a man goes the first two years to learn to be a soldier, and the next two years to be an officer, while we turn the thing the other end about. We send out these college graduates to be full-fledged engineers when they know nothing of the material upon which they operate. Engineering is not learned in four years, though some think it is learned in four weeks. Engineering is a progressive science. What is good engineering to day is obsolete to-morrow. Look at electrical engineering. I am no electrical engineer, though I am just now engineering a big electric plant. (Laughter.) I want to develop 4,000 H.P., half water and half steam. I will put the motion to the line shafts, and they can get their electrical expert for the electrical portion. There are so many instances where my experience with college graduates has been that they did not know how to put the transit or the level together mechanically. Why, last week I had occasion to have run over a survey where a surveyor had put in iron pins to locate the boundaries, and my excavation required some of the pins to be removed. I said, "Set me off 25-foot offsets, for I am going to take some of your pins out, for I have 35 feet of rocks to go through." I said, "Give me the offsets." He had a transit with one bulb on. I said, "Where is your other bulb?" He said, "I have sent it to Gurley's to have the glass put in." Suppose he was a hundred miles from any place, what then? I said, "What are you going to do?" He said, "I will flag over these pins." I said, "But you have an elevation of 80 feet; where is your flag going to land you?" He said, "I don't know how to fix it." I said, "I will tell you how to fix it. You have got only one tube there; swing your transit a quarter of a

turn and level it both ways by repeating, but, for heaven's sake, have your transit level."

Mr. Oberlin Smith.—If Mr. Strong will bring these bright locomotive men in I will, if they have the usual credentials, be among the first to vote for them as members of this Society. If in my remarks I have shown an undue lack of respect for blue overalls, it is, perhaps, because I generally (after the first day or two) wore my own *black*—at least my friends said so, particularly my maiden sister.

Mr. Cartwright.—The graduate never gets his face or his clothes black either.

Mr. E. A. Darling.—I would like to say a few words, Mr. President, on this question of the utility of the college graduate in engineering practice.

I suppose that the feeling sometimes shown by what are called practical engineers on the question arises largely from the conviction on their part that the graduated engineer is the man of the future. He is bound to be. We know that technical education is not going backward. I do not think that any reasonable man will expect a graduate from a technical college to go right in and take hold of some intricate engineering problem and carry it to a successful issue. As I heard President Adams, of Cornell, once remark, "All the technical college can hope to do is to bring the young man up to the crossing of a number of avenues, and give him a chance to look down these avenues and see what there is before him." It cannot be expected that in four years an experienced mechanical engineer will be turned out.

Now, in the learned professions that have been referred to, Law and Medicine, if you will bear in mind, the young doctor when he graduates gets the degree of M.D., and his degree is as good as that of the practitioner of thirty or forty years' standing. No one expects that that young graduate will undertake to carry to a successful conclusion a difficult surgical operation. He has his way to make; but he has certain rights and privileges which are accorded to him by the profession in general, and we have our County Medical Societies, and we have our Bar Association, to protect him in his practice, and to provide a certain code of ethics in both cases. After the lawyer has passed his bar examination he is entitled to practise. No one expects that he will be a Choate or an Evarts on the spot.

I think Mr. Porter's point has been well taken; if, as he suggests, the term Mechanical Engineer indicated a known quantity; if it told that the holder of the title knew certain things, what he might know more being largely a matter of conjecture, but that he at least knew so much, it would improve the status of the profession considerably.

Mr. W. S. Rogers.—Mr. Oberlin Smith advises that we rob the locomotive engineer of his title. If I remember aright the locomotive runner was the first to appropriate the title of engineer in this country outside of the military service, and I do not think Chief Arthur, with his 20,000 followers, is going to relinquish it now under any circumstances unless we give him something more glittering.

In regard to the time required to make an "engineer," it all depends on the material, and as to "protection of the graduated engineer," protection is needed both ways in many cases. When I was under that prince of engineers, Anthony Victorin, in the drawing-room at Watervliet Arsenal, several students from Rensselaer Institute came there for summer practice. Mr. Victorin told me to put them to work, and I felt somewhat demoralized, for I had some experience with the full-fledged graduate in days gone by. At the end of a week I actually loved those youngsters. They came there to put in practice the theories that had been unfolded to them by the professors and become disciplined, and they put in their eight and sometimes fourteen hours per day with a steadiness and care that would shame some older heads.

Knowing my own disabilities from the lack of that college finish which I was unable to obtain, what I feel bad about is that so many young men with tastes and desires in this direction —I have them in my own shop—apprentices containing the material engineers are made of, are barred from the technical course from lack of means. If the graduate, or rather the "technical" engineer, is afraid he does not receive all proper respect from his brother, the "practical" engineer, I would suggest the appointment of a grievance committee to adjust matters.

As the engineer averages up at present, he is a cripple. The technical fellow gets cheated every day by the ordinary workman because he does not know the extreme limit to which he can push his work; consequently, it costs more. The practical chap is not familiar with the reasons why or theories, and either

has to pay to find out or grope along in the darkness blindly and lose time. The former is crippled in his arms, the latter in his head, but exercising patience and coming together in harmony, the perfect engineer will come in time and this generation of cripples will have passed away.

Mr. Gus. C. Henning.—I would like to call attention to a slight error in the paper on page 490. It is stated that the Brooklyn Polytechnic began the education of mechanical engineers between 1866 and 1872. That is a mistake. The Brooklyn Polytechnic did not at that time, and does not now, educate mechanical engineers. I should like to have that correction made, because our *Transactions* should be correct and reliable.

Mr. Cartwright.—I would suggest that we resolve ourselves each into a committee of one to think of this thing truthfully and earnestly, and let us see if we cannot get at some solution; not what the title shall be, but how best to accomplish the end of building up an engineer. Now let us, at the next meeting where we meet to discuss this, each one think of this thing, think of it earnestly, and let us see if we cannot do something for the rising generation of engineers.

*Mr. H. F. J. Porter.**—Since it is my privilege to close the discussion which my paper, if accomplishing nothing else, has made prolix, I must confess that I am very agreeably disappointed that none of those who have participated have taken exception to the main points, while but few have disagreed with me in minor details.

In order that we may see what it is all about, I will take the liberty of stripping the remarks of each member of their decorative drapery and boiling down the embodied ideas to a dry sediment for analysis. Where I find an argument against my suggestions I will, in a few words, attempt to meet it.

Beginning with an epitome of my own paper, my premises are in effect that—

The standing of *Engineering* can be improved.

My suggestions are—

That the subject be referred to the committee now in charge of the Engineering Congress to be held in Chicago in August next, with the request that it be properly worked up and presented there for discussion.

That the committee recommend that the Congress appoint a committee com-

* Author's Closure, under the Rules.

posed of representative members of the various branches of the profession which should exist perpetually and act under a defined policy.

The duties of such a committee should be to standardize admission to the profession, and divide the field of practice into recognized specialties according to the changing demands of the times; to establish a code of ethics and to regulate fees for services rendered. The committee should enforce or oppose legislation affecting the profession. It should establish standards, gauges, methods of testing, etc. It should, in fact, be the recognized tribunal to which all questions affecting the profession should be referred.

To this Professor Thurston says—

1. See that selection brings into the profession only those who are fitted for it.
2. See that the preliminary training of the candidate, though giving him a general education, fits him for at least one specialty.
3. See that the practice of the candidate is confined to the specialty for which he is fitted.
4. The ideal preparation should include, first, a general education, and, second, a professional training.
5. Good education, good professional training, careful selection, and established professional ethics will preserve a satisfactory status of which we shall have reason to be proud.
6. The schools will place the mark of competence on their men; the profession has for its special duty the sustaining of high ideals and of good work among its members.

In all of the above Professor Thurston is in perfect accord with what I think and say, but after advising that the above work be attended to, he unexpectedly says that,

If left to itself, time will accomplish it.

It seems to me that a properly qualified committee could guide and secure the accomplishment of this work more effectively than if it is left to haphazard settlement.

Mr. J. T. Hawkins

Is prepared to indorse my paper as far as it goes throughout. He believes that something like the course recommended is at this time most desirable. He thinks that the profession should be divided into hypothetical and creative engineers, and goes into elaborate detail in favor of these divisions.

This type of division seems to me to be more of a grading of engineers in their respective specialties. Some men are more theoretical than practical in the bent of their pursuits, and form the division suggested as hypothetical. The hypothetical engineer is a statistician whose ability as a physicist and mathematician allows him to analyze and make deductions and formulate rules. It is to him that the *creative* engineer gives the data, and after they are properly formulated acts upon them, in giving to the world the result of his adaptations.

Mr. J. H. Cooper says that

> Engineers will be aided by having proper channels for preserving, for the use of the profession, records and methods of work.

It could be the duty of the committee to preserve such records in a recognized Engineering Library.

Mr. Geo. Hill says that

> The improvement of the status of the engineer is of great importance, not only to every member of the profession, but to the community at large. In the professions of medicine and law there is a body which, after an examination, issues a license to practise. This is a good thing.

Then he goes on to say:

> But it will not be maintained that by reason of this license all of the incompetent doctors and lawyers are weeded out. The average man knows of plenty of ignoramuses who are injurious to their profession. Professional etiquette does not hinder these men from glaring advertisement to the benefit of their pockets. A diploma or license from a particular source does not give them any particular prestige.

All of this is at least subject to argument. If it is as represented, it does not follow that it could not be remedied if properly adjusted.

I hold, however, that the quack doctor or the incompetent lawyer has to ignore professional etiquette to exist, and is practically relegated beyond the pale of his profession when he resorts to glaring advertisement, thus making himself known to the public for what he is.

Mr. Hill acknowledges, however, that

> This same diploma or license is beneficial to the engineer, in so far as it requires a more perfect understanding of his subject, and puts him in the way of enlarging his acquaintance.

When Mr. Hill discusses my division of the engineering field, and instances its effect upon an architect's office, he does not grasp my proposition in its entirety. There is no "architect" in my revision, he being replaced by the "static engineer," who would, when he needed advice in certain directions, call in specialists to his office.

Mr. Hill finally thinks that

> The standard of mechanical engineering ought to be raised, and that its members ought to be graded. Apparently, he would force them all into the American Society of Mechanical Engineers, under appropriate grades.

Possibly, if this could be accomplished and the members of the other branches of engineering could be forced into their

respective societies under their respective grades, the result I outline in my paper might be accomplished, but I fear that the machinery to be worked would be too cumbersome, to say the least.

Mr. B. Le Van instances

The advisability of conferring the degree upon men not graduates of technical schools.

Mr. T. W. Draper advises

The raising of the grade of technical schools, and by this I presume he would recommend making the standard of graduation equal in all of them. He does not, however, go further than to say that he thinks time will bring this about.

In this he probably is right, but future generations will enjoy the benefits which might, under my method, occur sooner.

Mr. Oberlin Smith advises

Raising the standard of the profession, grading the members, etc. He indorses my suggestion to have the societies join in an effort to start a reform by appointing committees for conference, and bringing up the subject before the Engineering Congress at the Columbian Exposition.

Mr. Durfee infers that

Admission to membership in the American Society of Mechanical Engineers virtually confers upon those admitted the title of mechanical engineer.

It seems to me that if any such impression is going abroad it should be the duty of this Society to immediately take steps to suppress it, as there is no foundation for such a construction of our articles of constitution.

Mr. Spaulding thinks that

Graduates of engineering schools should not have the full title of engineer until they have obtained a certain amount of experience in the field.

Mr. Kent thinks that

Where the engineering schools are lengthening their technical course they are working in the right direction, but that graduates should engage in practical work afterward.

Where Mr. Kent criticises my division of the engineering field, he falls into the error of not arguing from my premises.

He thinks that an "iron works" engineer should hold nine licenses in as many specialties.

I have no such division as "iron works engineer," but I think that any large and well-organized iron works should have in its employ a "manufacturing," a "metallurgical," and a "dynamic engineer." If the iron mines are controlled by the company, most certainly a "mining engineer" should be in charge of them For further incidental work in the line of constructing

buildings, railroads, etc., the "static" and "land" engineer could be called in as specialists.

Mr. Kent does not seem to be able to divest his mind of the plan at present in vogue of having one engineer with a smattering of knowledge in all branches of the profession attend to all the engineering requirements of a works, while good men, better fitted for these special duties, are hunting about for something to do. This system is to my mind most reprehensible.

Mr. Strong emphasizes the fact that

Graduates from engineering schools are not practical enough until they have had subsequent experience in the field or shop.

He also argues that

The man who has risen from the ranks ought to have a right to equality in every way with the graduate of the technical school.

Mr. Cartwright is very emphatic in his opinion that

The *work* of an engineer is what should qualify him for his position in the profession.

Mr. Darling thinks that

The title "mechanical engineer" should act as a certificate of a certain defined standard of ability.

Mr. Rogers feels that

Both the man not technically educated, and the man who is, are to a certain extent cripples. Time will bring about the more perfect harmonizing of the two kinds, and the perfect engineer will result.

Those whose opinions are quoted above are men representative of different branches of mechanical engineering; and I gather from the above expressions that there is a unanimity of sentiment that the standing of the profession can be raised.

I hope that the Society will consider my proposition favorably, and appoint as a committee its representatives on the General Committee of Engineering Societies, authorizing it to coöperate with the other members of that committee in bringing the subject before the Engineering Congress at the World's Columbian Exposition of '93.

No. 525—97.

Is the weaving-shed form of construction well adapted for a modern machine shop?

Prof. John E. Sweet.—While there may be but little of definite importance found in the following, except such as derived from

experience obtained in designing, building, and operating in a single structure, the paper is based upon the above broad title in the hope that those of the posted members who have builded "better (or worse) than they knew" will enrich the discussion with their ideas and experience.

When the size and form of a shop have to conform to the lot upon which it is located, then it will depend upon the genius of the designer for its success; but if the designer simply builds the building as large as the lot, and leaves the arrangement for future study, or fate, it is liable to be a failure. An architect, unless he be one who has made a special study of it, is liable to do more harm than good.

If one has an open field at his command, an opportunity is open to study out the best plan. Building shops by the mile, and cutting them off in so many hundred-feet pieces, and setting them down like a gridiron, a Greek cross, or a gravel fork, may not be just the best thing to do.

There is this, it is true, that one can get them only about so dark if limited to a moderate width and held to a goodly half-useless space between the branches. Ventilation is good, but it makes long distances to travel between the different departments, and that is very bad when a place is so small that one man has more than one department under his control. In many respects the weaving-shed plan—that is, a one-story structure in sections, separately roofed, with the north sloping side of glass—has advantages. As to ventilation, in its simplest form it may be inferior, but the ventilation is easily controlled when the problem is once fairly attacked.

Common and fashionable as is the salt-block construction—that is, a central high section with a gallery on either side—this form, when used in a shop so small that one foreman has control of all the machinery, has this disadvantage, that he has to "see-saw" across from side to side, worming his way through the erecting section, whereas, with the erecting floor at one side, the machine tools are concentrated. With a small shop, too, the climbing up and down stairs is not only a nuisance, but absolutely costly. Things can be moved in an elevator very cheaply, but carting, loading, unloading, and carting again spoils the economy. It is doubtful if there is any saving in two or more storied shops, except in real estate, and when as much ground has to be left idle to get light as is covered by buildings,

then the saving in real estate is small, unless the buildings are more than two stories in height.

The advantage of the one-story weaving-shed roof plan is that the building can be extended to any length in either direction, and to any width in one direction, without interference with light, with advantage in heating, and with the advantage of having everything on one floor, and that floor a solid one. The trouble apprehended from ice, snow, and water has no foundation in fact, and if dealt with in the way described later, need not give one a moment's anxiety.

The section for travelling cranes can be of any height and width, without interfering with the weaving-shed structure or light, by placing it on the south side.

While there is getting to be some really genuine permanent foundation building done in this country, it is mostly confined to the larger commercial cities, and has not as yet found its way into the workshops or small towns.

The principles are easy to understand. If the earth throughout the entire structure has equal sustaining power, then the area of the foundation under the different parts should be in proportion to their loads, and the centre of the foundation should be directly under the centre of pressure. Or, to emphasize the ideas, it is just as detrimental to put too much foundation under the light parts of a building as too little under a heavy one, and worse to have a load rest on one side of a wide foundation than on the centre of a too narrow one.

Machine-shop floors are a problem, and while those made of dirt, like some of the French ones, seem to last the longest, they are hardly satisfactory; neither are the English brick floors. The following, used in the works of the Straight Line Engine Co., has so far given good satisfaction. The earth was excavated to a depth of 27 inches below the floor line, and rolled with a heavy roller, the soft places filled, and again rolled and levelled. Building-stones of the cheapest sort—that is, stone too poor for foundation walls—were dumped on the ground, and men set to sorting the largest pieces and closely packing them on the ground; a strip of two or three feet of this work was kept in advance of the other filling, so as to insure its solid character. Upon this was a layer of the smaller stone, then broken stone, coarse gravel, fine gravel, and, lastly, sand. There is no other possible way in which each grade can be made to

retain its place, except by reversing the process and putting the larger above the smaller. If mixed indiscriminately, the fine will work to the bottom and the coarse come to the top. By following the plan given, a solid foundation is secured, upon which is placed nothing but 2-inch hemlock plank running one way, with a 1-inch planed and jointed, but not matched, floor running the other way. The advantage of the thin top is that when there is a hole worn through, it is but an inch deep at the most, and the plain strips of uniform width make it easy to repair. This makes a floor on which anything can be set anywhere, except the largest of the machine tools requiring separate foundations.

Some accounts of the English practice give 16 feet as the width of spans or bays, but in the works above mentioned 32 feet is used, 8 feet being the unit upon which the building is constructed. In a more extended plant, 10 or 12 feet would be proper. The posts are 8 feet or 16 feet between centres, and all the roof trusses 8 feet. The roof is simply 1½-inch pine plank, 16 feet long, planed and matched, planed side down, nailed to thin strips of basswood riveted between the two angle-irons which form the rafters, covered with ribbed, not corrugated, iron; and the flat roof over the travelling-crane section is the same, except the gravel roof.

In the construction of the posts and roof, by making each member of two pieces $\frac{5}{8}$ or $\frac{3}{4}$ inch apart, between which bolts can be passed, a convenient means is at hand to fasten anything anywhere.

The iron structure is more expensive than wood, but lighter, exempt from fire, and, with the provision for bolt attachment above referred to, more convenient.

The trusses are strong enough to hold three or four tons besides the roof, so that any pieces of machinery or work which are liable to be handled can be raised by tackle attached to the trusses in whatever part of the place they may be.

The question of snow, which seems to be the bugbear to every one first thinking of the weaving-shed roof, is one requiring hardly a second thought. Making the gutter of cast-iron, as shown in Figs. 161 and 162, or any convenient shape, and putting it inside the building, with the heating pipes adjacent, is all which is required. Keeping the gutters clean is all there is to it, and snow and ice will thaw sooner in cast-iron than

on the wood planking when the heat comes from the lower side.

Eight feet between centres would seem to be too near together for posts, but by making benches 12 feet long, supported by two posts, leaving 4 feet spaces between the ends of the benches, the apparent objection vanishes where the bays are as wide as 32 feet.

In a building for large work, with 10 feet between trusses, the

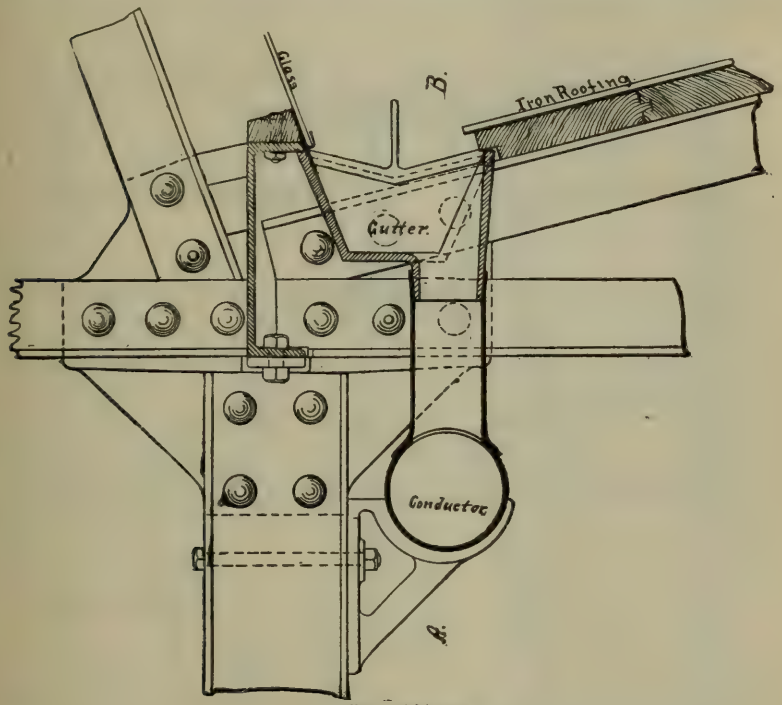


FIG. 161.

bays could easily be 40 or more feet, with 8 feet of glass on the northern slope.

The geometry of the roof is very simple: simply dividing the lower chord into four equal parts, and the rafter into four equal parts, and joining the points with the struts and braces (Fig. 163). While economy of material would dictate iron of different section and weight, to save bother we used all alike, and as the accidental loads are unknown quantities placed in unknown positions, perhaps that was as well as applied high science.

The accompanying cuts are self-explanatory (Figs. 165, 166).

In the weaving-shed system of lighting the annual cost for repairs of broken glass is practically *nil*, and in this connection the writer volunteers to say that he believes an erroneous idea is pretty universally prevalent in regard to the most economical size for lights of glass for shop-lighting. The theory is that the small-size lights for various reasons are the most economical. But after a long observation, the evidence to me is conclusive that the larger the lights the less the cost for repairs.

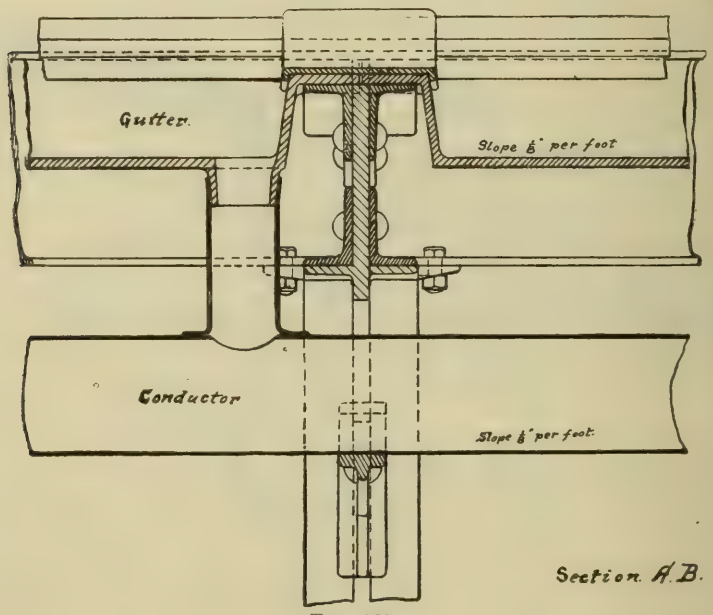


FIG. 162.

Large lights stand far more punishment, and the workmen have some respect for a light of glass which costs a dollar, but none whatever for 10 × 15 glass. Whether these are the reasons or not, the fact remains that where in one part of our works the annual breakage of 10 × 15 glass does not fall below 100, there is another part where the large lights were equally exposed, and there was but a single light broken in two years.

The writer's observations in this direction have not been confined to a single case, and it will be to the interest of those contemplating new buildings or changes to investigate this subject.

In the works mentioned, the main office is a fire-proof vault in

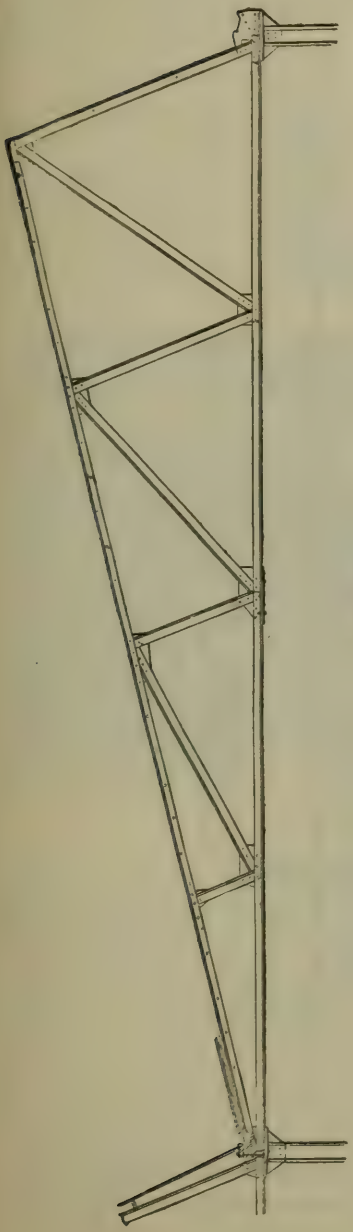
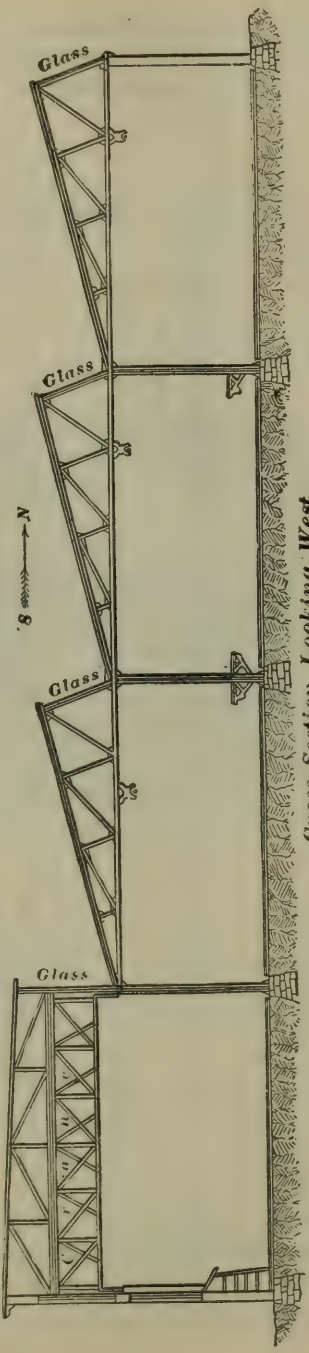


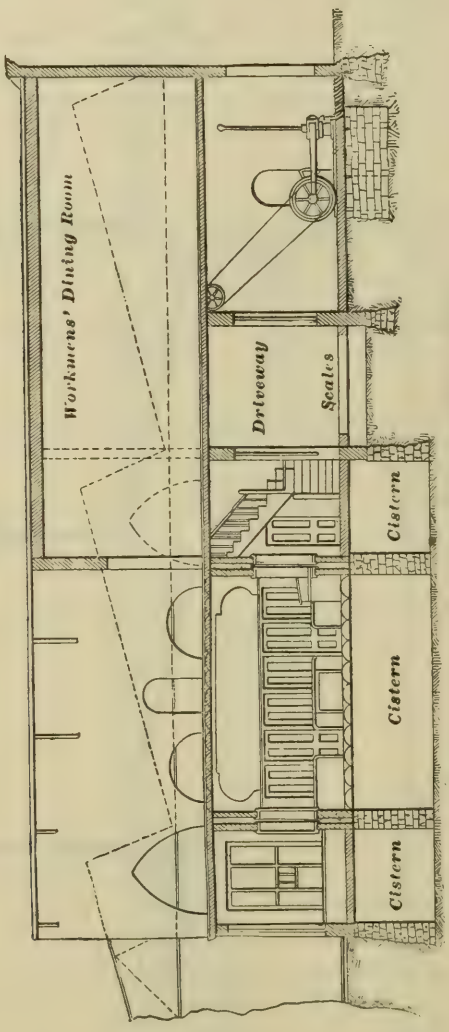
FIG. 163.



Cross Section Looking West.

FIG. 165.

effect. Drawings, books, and valuable papers are thus protected by simply closing the fire-proof doors, which are self-closing, in case of fire, if neglected. For small works this is better than a



Section through Office and Engine Room.

Fig. 164.

separate building, as it concentrates the supervision. Low partitions, or simply a railing, separate the pattern shop from testing floor and main shop, instead of closed rooms, with a great advantage (Fig. 164).

It leaves the whole place subject to observation, and the men work nearer ten hours a day when paid for ten hours, and are just as happy at night as if two hours out of the ten had been spent in visiting.

While visitors are always welcome, it is more than probable that we have less visiting than other shops of the same size.

Mr. C. J. H. Woodbury.—In a building used for manufacturing purposes, and one story in height, the floor and the roof are two of the most important subjects, and I propose to limit my discussion to those features of the paper. For a floor where the working people wear leather shoes, it goes without saying that

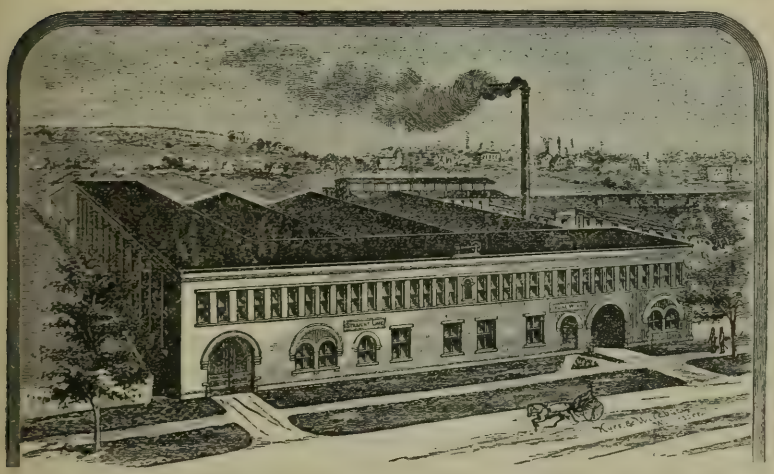


Fig. 166.

wood is the only available material, and for that kind of buildings we must place that wood with due reference to questions of wear on the upper surface and defence against dry rot underneath. Those questions are, of course, to be answered from experience and that alone, and so I shall beg to refer to some matters of precedent on this subject. The method of placing stone on the floor site, and reducing it finer and finer until the upper courses are gravel, will no doubt answer very well for places like the meadows of Syracuse; but in many other places where springs or small water-courses traverse the site of the works, it is necessary to provide for the removal of any possible accumulation of water by a carefully organized system of drain-

age. Dampness arising from water will promote the growth of decay, I believe, more rapidly than actual contact with water.

As an example of this difference, I would cite the case of the wheel-pit of a mill where timber braces against a seamy ledge, which was kept wet by streams of water issuing from the openings, were sound at the ends, which were kept constantly wet, but the middle portions of these beams, which were exposed only to the damp vapor arising from the water, showed a considerable decay.

I have known floors which were placed on small stone laid similarly to the method described in this paper, to last for certainly over twenty-five years, although the site abounded in springs; but in addition to free drainage, the further precaution of placing a layer of air-slaked lime, half an inch to an inch in depth, upon the gravel before laying the floor, proved to be an additional protection to the floor: for lime is a preservative of wood as long as it can be kept in contact with the wood. Of course, if it is washed away, the wood will return to its original condition, being without defence. As an example of the antiseptic powers of lime in the preservation of wood, I would say that I doubt if anybody ever saw a decayed lath which had been in service with the mortar about it. There are other methods of placing floors right against the earth in these one-story buildings. The use of Portland cement, upon which the flooring is placed, has been tried by a great many, with the result that spruce or hemlock will decay in five or six years. If coal-tar concrete is used, the floors will last a great while. I know that they have been in use for over twenty-five years without any indication of decay. It is unnecessary to place sleepers for such flooring, excepting such strips as may be necessary in order to lay the concrete perfectly level, and do not act as a support. In a building examined a short time ago in the course of some changes in a mill at Waltham, Mass., situated on a meadow and through which water was no doubt percolating from the canal less than one hundred feet distant, it was found that the floor was made with a very weak cement, probably one part of cement to ten or twelve of sand, and over that thickness the cement was mopped with melted coal-tar. Upon this the flooring of 1½-inch spruce was laid, and above that the hard-wood floor. This spruce is in perfectly sound condition, retaining its original elasticity and strength, without any indication of decay, after a lapse of forty years of continuous service. For the

floor in the boiler shop of a locomotive works, where very severe conditions of wear were applied, the whole area was paved with cobble stones, and upon the pavement a coal-tar concrete 6 inches thick was laid; and upon this the lower flooring of oak plank, 4 inches thick, was laid, and the top flooring consisted of another row of oak plank 2 inches thick, laid at right angles to the lower floor; and the result has been that there was a floor which has not needed any repairs, and resists all the great shocks and accidents of the service to which it has been subjected during the past ten years.

Another type of machine-shop floor, at Philadelphia, was made by putting moulding sand on the site and laying sills on loose bricks at intervals, and leaving a very small space around these beams, which was filled with melted resin. The top of the sand was levelled off at about an inch below the top of the beams. The floor plank, containing numerous holes, were placed across the beams and then resin was melted and poured through those holes, which were about a yard apart in each direction, so that the floor and beams all rested on resin, and this floor has done excellent service for a great many years.

Professor Sweet has been over-modest in his paper, because he has not only omitted many points of great ingenuity and value, with which I am somewhat familiar, in regard to the shop, but he has neglected to say that the result of his skill in regard to the roof has modified the European ridge and furrow roof in such a manner as to conform to the conditions of our American climate. I think there is no doubt that the ridge and furrow roof will give the softest and most diffused light, without the glare which is inevitable with skylights, or the monitor roof. It appears to me, however, that the roof would have been still better adapted to resist the severity of the American climate if, instead of being $1\frac{1}{2}$ inches thick, it were $2\frac{1}{2}$ or possibly 3, doing away with the purlins, excepting one beam across the middle of the 16-foot bay, so that the plank would be supported once in every 8 feet instead of by the purlins. It would require a slightly larger amount of timber, and it would be installed with a less amount of labor.

The method of draining this roof is very ingenious, but is it not done at the expense of the heating of the room, and would it not be better to have the trough of the roof or the gutters well protected by wood, and then using either closed or perforated steam-pipes, lying along the gutter for blowing steam

whenever there was any expectancy of the formation of ice at that point?

I made some reference to the method of lighting one-story shops, and would make reference to tests which have recently been made on the diffusion of light by various forms of rough glass, merely by using a photometric dark room in which the light was admitted by a slit upon this glass. With a perfectly straight glass the photograph would be merely a rectangle; but with any of the ribbed glasses there would be more or less dispersion of light. One can, in that way, obtain a measure of the value of the various kinds of glass, both as to the amount of light transmitted and also as to its dispersion, far better than by direct observation. If one compares a set of such photographs with the inferences which one would draw by simply looking upon such dispersed rays, he will find how much more accurate the photograph was than any method of observation.

Another method of testing the illumination of a building of this nature, is to take a photograph and watch the definition of the brickwork at the farther end of the building. That is an exceedingly good measure, both as regards shadows and the clearness of illumination.

Professor Sweet, by the way, has omitted one other matter, and that is in regard to his method of deciding the question as to the relative merits of different methods of roof covering. The various slopes of this building and portions of the flat roof are, I understand, all covered with different kinds of roof material, and although the story may be a very long one before the ultimate results are reached, still if the shop is not burned it will inevitably give valuable information by way of direct comparison of the manner in which the various kinds of roof will withstand the attacks of time.

Mr. J. F. Holloway.—It is known to some here that for many years I was connected with an establishment whose distinctive mark was, that it did not have very many modern improvements, and it is for that reason I wanted to speak of the floor which we had used of late years. The works having been built in 1833, and the surroundings not permitting very great extension, we had to get along the best we could with what we had. We had on our ground floor originally, sleepers buried in dirt or resting on small piers over which was the usual plank floor, and we had

the usual experience of people who used that sort of floor, the sleepers soon decayed by dry rot, and the planks curled up so that it was difficult to travel over them. There then came a time when wood paving was fashionable in Cleveland, and it occurred to me such a pavement might be good for the ground floor of a machine shop. As it happened, there had been a lot of wood paving blocks discarded by the city, for the reason that the timber had been deadened by fire, and was not, therefore, live timber when cut. I took up the old floor and sleepers, took off the top dirt and filled it in with clean, sharp sand ; on top of that we placed a layer of inch boards (which had been submerged in hot dead oil and coal tar) lengthwise, then another layer of boards, similarly treated, crosswise. Then on top of that we took the 6-inch lengths of wood paving blocks discarded by the city, and dipped them in dead oil and coal tar, and placed them close together with the end grain up, and the result was we had about the only good thing we could brag of in that establishment, a floor. It proved a very successful ground floor, was comfortable for the men, very good for drawing heavy loads over, and it lasted a good many years.

No. 525—98.

To what extent can the milling-machine be used to replace the planer in daily operation?

Mr. W. S. Rogers.—In the present day, when old machinery has served its allotted time of usefulness in the shop and must be replaced by tools replete with most modern ideas, it is a matter of no small moment to every practical, progressive shop-director having the responsibility of the semi-annual dividends thrust upon his shoulders, to determine just what type of machines to select which will be best adapted to his special line of work.

For example, suppose work has always been done on planers, and they are peculiarly adapted to it, would it be advisable to replace the old ones with new ones having latest improvements and added strength? If so, what will be the percentage of gain in time over those already in use? Or shall a milling-machine be the tool to be placed on trial to shorten the present hours of work performance? And also, what type?—not whose make. In all the written data relating to milling-machines and their many good qualities, the writer has been unable to discover any-

thing which would enlighten him in such manner that he could know intelligently to a certainty which type of machine would be the most desirable for the class of work to be operated upon, and while investigating preparatory to purchasing, in answer to the all-important question, How much work will this milling machine perform in a given length of time, and how will that amount compare with the work from the planer in the same interval? the builders of these machine tools give nothing definite whereon we may base our calculations, but confine themselves generally to the superiority of their manufacture over competitors—facts we always concede. In the particular instance in question, one manufacturer of both planers and milling-machines, of extended experience, and who knew from personal observation just what the class of work was, expressed himself favorable to the planer as being the machine best adapted for it. However, a final decision being made in favor of the milling-machine, and the type known as a "slabber" being chosen, it was bought and placed in position in the works, especial attention being given to its foundation, and warning being given to its maker that it would be subjected to the severest duties in its battle for supremacy over its rival, the planer, and the true merits of the milling-machine demonstrated in comparison, if possible. I would like to add in parentheses, I have always thought the builders of this especial machine were a little bit more slack about it than they would have been had they not received our "warnings."

The planer used in this test is of modern build (being about three years old), carries two heads, and is 30 × 30 inches × 8 feet, having a table travel of 27 feet per minute. The tools used are Mushet's steel, one and one-half inches stock. Both machines are fully equipped with chucks and clamping devices for suitably holding the work, and in charge of first-class mechanics of long experience, and between whom considerable rivalry exists. The favorable results from the milling-machine in comparison with the planer are somewhat surprising, even to those who know it best.

Eight pieces of cast-iron, 18 inches long, having a surface 8½ inches wide and 1¼ inches down each side, to be rough finished on the face and to size on the sides, are done on the planer in 4½ hours, the pieces being placed on the platen in two rows, and both heads being used simultaneously. The time required

by the milling-machine was just 41 minutes, straddle-mill cutters being used and one casting being operated upon at a time, the amount of metal removed being about one-sixteenth of an inch in both cases.

Another class of work is cast-iron strips 16 inches long, $\frac{1}{2}$ inch thick, and $1\frac{1}{2}$ inches wide, to be rough finished all over. The best time made on the planers was found to be at the rate of 4 every 36 minutes, while the milling-machine finishes 6 every 6 minutes. Still another class of work was narrow strips, having lugs on their outer ends, to be finished smooth and to size on the lugs, between them, and one inch inside of them, on the flat surface. The best time on record from the planers was 4 in 28 minutes; the milling-machine's daily records give us 8 of them every 4 minutes. The planers in this case were small modern machines, carrying single heads and having a cutting speed of 22 feet per minute. The spindle of the milling-machine makes 34 revolutions per minute, while the platen travels 13 inches in the same interval. The platen travel per minute has been doubled after coming to the works without affecting the cutter rotation. Another item of importance brought out is the fact that the cutters are colder and hold their cutting qualities longer since the speed of the platen was increased and the work forced harder against them, thus conclusively demonstrating, to the writer at least, that it is frictional contact which tends to dull the cutters and wear them away by grinding, and not the actual work performed. Memoranda kept during the past year also indicate the cost for renewals for cutters and grinding to be about 25% less than the running expenses for planer tools.

Another important practical result brought about by the milling-machine after it was in full service was the total abandonment of three planers and one shaper, previously used on this work, all of which now goes to the miller, and an increase in the capacity of production of over 25%; at the same time bringing about a greater uniformity of work than could possibly have existed under previous conditions, and, lastly, causing a reduction in the pay-roll, not from a reduction of wages but because fewer men are required.

To the writer, these figures from the milling-machine are neither conclusive nor satisfactory. I think the platen travel of this type of machine can be increased to 20 inches per minute

under the same conditions for "roughing off" work and leaving enough for finishing. I speak now only of cast-iron; steel and other metals would be slower in proportion. There are to-day a thousand and one varieties of heavy work being done slowly on planers which should be done rapidly on milling-machines, but the milling-machine to do this must be designed and patterned closely upon the lines of the modern planer, and must universally reach over and around the work on the platen, and be as easy to handle and operate as the present planer is to-day, and I am also convinced that a milling-machine can be built that will take off metal at the rate of 36 inches per minute—nor need it be so very high in purchase price either.

Another thought brought out from close association with a miller is the inconvenience at present existing for clamping and chucking the work. If it requires 20 minutes to clamp a piece on the planer and 1 hour to plane it, and only requires 20 minutes' milling, but 1 hour is used up in clamping it securely on the miller, the latter becomes an expensive tool and all the argument is in favor of the planer.

I have said nothing about the overhung-arm type of milling-machine in this paper, as it covers a field of its own in competition with small planers, shapers, and slotters, doing nice work and reasonably rapid, but as yet not up to what its possibilities are, the reasons being chiefly that it is lacking in rigidity and strength in its component parts.

Fig. 196.

Mr. Gus. C. Henning.—I have a few figures to add in regard to the work that can be done with a properly constructed milling tool. I have not been able to get the data of what a planer would do on similar work. Fig. 196 shows a form of cutter so gapped that three or four teeth cut one ring. The point is to get the cutting edges of the teeth to do the same work at all points.

There is a similar cutter in use, which has a sharp corner at one end of the tooth and a dull corner at the other. The result is that the sharp corner wears rapidly, or breaks off. In the cutter shown the angles are normal to the cutting edge.

On the milling machine three different cutters were used, all of similar design and identical dimensions, which were three inches diameter, six inches length, and about one and a half inches hole. They were all driven by the same power, and at the same rate of revolution; two were of Brown & Sharpe pattern and make, and one of Alfred Muir's pattern and make. The table gives results obtained.

Kind.	Depth of Cut.	Width of Cut.	Feed of Work.
Brown & Sharpe Cutter, No. 1.....	0.20 in.	5½ in.	2½ in. per minute
Brown & Sharpe Cutter, No. 2.....	0.24 in.	5½ in.	2½ in. per minute
Alfred Muir Cutter.....	0.21 in.	5½ in.	2½ in. per minute

The work was similar pieces of cast-iron, machine-tool beds, and the cutters were similar to this Muir cutter (shown in Fig. 196).

Mr. Oberlin Smith.—I want to ask for some information. Can anybody here tell me whether work of this kind (sketching on blackboard), it being a cross section of a cast-iron female dovetail in which slides the ram of a punching press, can be done more successfully in a milling machine than a planer. These dovetails are, perhaps, from four to fourteen inches wide, and from one to two inches deep, the angle being 45°? Can an ordinary conical cutter of the kind shown, or some other cutter, perhaps one made with small teeth, be used at so sharp an angle without the corners breaking off? The groove here shown in the internal corner is desirable as a clearance groove, to keep the ram wearing better. If it could be milled perfectly sharp, or slightly rounded only in the corner, that would do instead. But although I fully believe that in a great many kinds of work milling is better than planing, I am not quite sure whether this dovetailed work can be done cheaply in that way. Can those Muir cutters be purchased in the market?

Mr. Henning.—I suppose so. You can get them from Manchester. Brown & Sharpe make some cutters like that.

Mr. Charles E. Lipe.—I have had considerable experience

with milling work, and I have never found any trouble with cutters breaking when the angle of the cut was 60° instead of 45°. I have made a limited use of the angle of 45°, but the cutters are not so strong, and are more liable to break, although there is no trouble in doing the work if care is taken not to crowd them too hard.

Mr. Henning.—William Muir's Sons, of Manchester, make cutters for such work, and they are very successful with that style of cutter. I also passed around a reamer which was designed on the same principle as the cutter, and it will be seen that it is practically a mill, and which goes through the metal by actually cutting out the chips all the way through and leaving a perfectly smooth hole. The cutting edge is shaped like the edge of any tool properly backed off, and correct in every particular according to theoretical considerations.

Mr. W. S. Rogers.—In regard to cutters, we have done no experimenting with them whatever, but have used the commercial types now on the market; but I think the one described by Mr. Henning is "toothed" on correct principles and in accordance with modern practice. I do not say, as many do regarding the locomotive link, that "it must go," for I do not believe it, neither do I believe that the planer must go. We do work in our shop on planers that others do on milling machines, because we know from experience that the finished work gives better results and satisfaction in service in this particular case when it is done by the planer; but the milling machine's capacity is not thoroughly understood, nor its real value appreciated by those who build it, or those who use it.

With reference to Mr. Smith's sketch, if an upright angle cutter is used to mill the angle, leaving out the clearance groove, then a face mill for the higher surface, and perform the same operation on those two lower surfaces, doing each separately, I say the miller is not the machine. The planer will excel in this case, and do nearly double the amount of work. But the milling machine can be made so that these four operations can all be performed at once, including the angle. Under these conditions it becomes the superior by far of the planer, provided the work can be fastened and removed as rapidly as is done upon planers, and the machine itself is as convenient to operate. From data obtained at Watervliet Arsenal, in the construction of the large twelve-inch built-up

steel rifles, I find they are using the milling machine in place of the lathe. The obdurators are now milled in two hours, the time previously required by the lathe being about twelve hours, while the breech-plates for the twelve-inch guns are now milled in eight hours, which is a gain in time over the lathes of over forty-eight hours. We are also arranging another class of work that has always been done on planers for the miller. The best time possible now on the planer is seven and one-half hours. We know it can be performed by the milling machine in two hours.

Mr. Oberlin Smith.—You would not advise putting that clearance groove in?

Mr. Rogers.—No; for that class of work I believe I would leave the clearance groove out and put a fillet in its place, making the sliding ram fitting this dovetail, as shown in the sketch, so that it would have slight clearance where the fillet is. This would make a stronger bearing of the dovetailed part and accomplish the same ends as at present. The milling cutter could be then made strong and not self-destroying. The work, as sketched by Mr. Smith, *should* be done on the milling machine, but the great drawback to doing it lies in the fact that there is no such machine on the market having the capacity and range for this class of work.

When purchasing cutters, the same rule holds good in this respect as well as machines. You will gain more knowledge of what you want from visiting your neighbors' shops and seeing cutters at work than you will by going to see the cutter manufacturers. Chucks and jigs also enter as much into the success in rapid milling as either cutters or strong, convenient machines, and should be so designed for low cost and quick manipulation of work that they can be charged off the expense account at the earliest moment possible. Comparative performance data, kept from the milling machine for a period of months, would be surprising to many who now think they are making great profits from it, and induce them to push it forward to greater results.

PAPERS

OF THE

CHICAGO MEETING

(XXVIIth)

JULY 31 TO AUGUST 5, 1893.

BEING ALSO THE PAPERS PRESENTED BEFORE

THE SECTION OF MECHANICAL ENGINEERING

AT THE

WORLD'S COLUMBIAN CONGRESS OF ENGINEERING.

DXXVI.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

CHICAGO MEETING

(XXVIIth),

July 31st to August 5th, 1893.

The Twenty-seventh Meeting of the American Society of Mechanical Engineers was merged into and became the sessions of the Mechanical Engineering Section of the World's Columbian Congress of Engineering, held at the city of Chicago, Ill., during the period of the Columbian Exposition. This Congress had been projected by a committee appointed from eleven societies of American engineers to provide and control a headquarters in Chicago during the Exposition; and by appointment of the World's Congress Auxiliary, the Executive and General Committees for the Congress embraced the same persons who had received their authority from the engineering societies. By this simple procedure it became very easy to request the councils of the various national engineering societies to assume control of the matter of papers for the several sections of the Congress, which was ultimately divided into the following groups:

I. Civil Engineering.
II. Mechanical Engineering.
III. Mining Engineering.
IV. Metallurgical Engineering.
V. Engineering Education.
VI. Military Engineering.
VII. Marine and Naval Engineering.

This responsibility for the welfare of the mechanical section was accepted by the Council of the American Society of Mechanical Engineers, by resolution bearing date of January 21, 1892. The detail of management of the Congress was agreed upon by the executive officers of the sections and forwarded to the general committee for adoption, and the meeting of this Society in the spring of 1893 was made the session of the Mechanical Engineering Section.

The Congress was convened in the Memorial Art Palace in the city of Chicago, on the Lake Front Park, fronting on Michigan Avenue. The opening session of all the Congress was held on Monday morning, July 31st, at ten o'clock, in one of the large halls. President H. C. Bonney, of the Congress Auxiliary Committee, welcomed the delegates, and fitting responses were made on behalf of the American engineering societies and of foreign nations represented at the Congress. The sections thereupon separated to their assigned meeting-rooms for the business in hand.

The session of mechanical engineering was made the session of the American Society of Mechanical Engineers for its routine business, and no papers were read. The President announced the appointment, under Article 31 of the Rules, of the committee to nominate officers for the next Society year, and that the persons so chosen were :

Mr. Stephen W. Baldwin, of New York.
Mr. H. H. Suplee, of Connecticut.
Mr. John F. Wilcox, of Pennsylvania.
Mr. Harvey Middleton, of Illinois.
Mr. John A. Gray, of Ohio.

The Secretary then read the report of the Tellers of Election appointed under Article 13 of the Rules, as follows:

REPORT OF TELLERS OF ELECTION.

The undersigned were appointed a committee of the Council to act as Tellers (under Rule 13), to scrutinize and count the ballots cast for and against the candidates proposed for membership in the American Society of Mechanical Engineers, and seeking election before the Twenty-seventh Meeting, Chicago, Ill., 1893.

They have met upon the designated days in the office of the

Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the persons whose names appear on the appended list, to their respective grades.

There were 480 votes cast on the pink ballot, of which 15 were thrown out because of informalities (the members voting having failed to indorse the sealed envelope).

WM. H. WILEY,
C. W. HUNT, } *Tellers of Election.*

NEW YORK, *April* 3, 1893.

There were 437 votes cast on the yellow ballot, of which 10 were thrown out because of informalities (the members voting having failed to indorse the sealed envelope).

WM. H. WILEY,
C. W. HUNT, } *Tellers of Election.*

NEW YORK, *June* 1, 1893.

NEW YORK, *July* 24, 1893.

There were 455 votes cast on the green ballot, of which 17 were thrown out because of informalities (the members voting having failed to indorse the sealed envelope).

CHAS. W. HUNT,
WM. H. WILEY, } *Tellers of Election.*

July 25, 1893.

MEMBERS.

Almy, Darwin.....Providence, R. I.
Appleton, Thomas.....Chicago, Ill.
Baker, Chas. W .....New York City.
Baker, Frank D.....Denver, Colo.
Bement, Clarence E.....Lansing, Mich.
Camp, Geo. E .....Worcester, Mass.
Clarke, Fred. E .....Lawrence, Mass.
Colby, Albert L.....Bethlehem, Pa.
Coleman, George F.....Mt. Vernon, N. Y.
Connell, Jas. A.....New York City.
De la Calle, Victoriano.....Matanzas, Cuba.
Conrader, Rudolph.....Erie, Pa.
Dickson, James P.....Scranton, Pa.
Edwards, Levi T.....Haverford, Pa.
Elson, L. E.....New York City.
Fisher, Clark.....Trenton, N. J.

Firth, Wm. E. ..... Philadelphia, Pa.
Floyd, Frederick W. ..... New York City.
Fletcher, Andrew, Jr. ..... New York City.
Gause, Fred'k T. ..... New York City.
Greene, Levi R. ..... Cambridge, Mass.
Griffin, Chas. L. ..... Muskegon, Mich.
Haines, H. S. ..... New York City.
Hamilton, Jas. V. ..... Brooklyn, N. Y.
Harlow, Mellon S. ..... Johannisberg, S. Africa.
Heywood, Wm. A. ..... Baltimore, Md.
Higgins, Campbell P. ..... New York City.
Hildreth, Charles L. ..... Lowell, Mass.
Hinchman, Chas. R. ..... Joliet, Ill.
Hogan, Martin J. ..... Canton, O.
Jaques, Wm. H. ..... New York City.
Jewell, Chas. W. ..... Beaufort, S. C.
Landsing, Jang ..... Cleveland, O.
Lawton, M. A., Jr. ..... Chicago, Ill.
Lyon, Tracy ..... St. Paul, Minn.
Marshall, Waldo H. ..... Chicago, Ill.
Mix, Melville W. ..... Chicago, Ill.
Parkhurst, Chas. D. ..... West Troy, N. Y.
Rusby, Jno. M. ..... Jersey City, N. J.
Sargent, Fitz William ..... Chicago, Ill.
Sahlin, Axel ..... New York City.
Scott, Geo. H. ..... Worcester, Mass.
Searing, Hudson R. ..... New York City.
Shaw, Alton J. ..... Muskegon, Mich.
Street, Clement F. ..... Chicago, Ill.
Smith, Gilbert S. ..... Philadelphia, Pa.
Stafford, Edgar L. ..... Chicago, Ill.
Sinclair, Nisbet ..... Philadelphia, Pa.
Tweddell, Ralph H. ..... London, England.
Vail, Jonathan H. ..... New York City.
Warriner, Samuel D. ..... Wilkesbarre, Pa.
Ward, Geo. H. ..... New York City.
West, W. Franklin ..... Morris Heights, N. Y.
Wilke, Wm. C. ..... Philadelphia, Pa.

Members, 54.

ASSOCIATES.

Bonner, Wm. T. ..... Chicago, Ill.
Bragg, Chas. A. ..... Philadelphia, Pa.
Breen, James ..... Butte City, Mont.
Ingersoll, Winthrop ..... Rockford, Ill.
Riegel, John S. ..... Riegelsville, Pa.
Weaver, Norman R. ..... Chicago, Ill.
Wick, Henry ..... Youngstown, O.

Associates, 7.

PROMOTIONS TO FULL MEMBERSHIP.

Aller, Amos.....New York City.
Hobart, James C.....Cincinnati, O.
Lyal, Wm. L.....New York City.
Reist, H. G .....Lynn, Mass.
Suter, Geo. A.....New York City.
Wilcox, Wallace J.....Blacksburg, S. C.

JUNIORS.

Anderson, Jas. C.....Brooklyn, N. Y.
Atkins, Harold B.....New York City.
Cornelius, Wm. A.....Pittsburg, Pa.
Corry, Harry T .....Ithaca, N. Y.
Escobar, Juan de la Cruz.....Matanzas, Cuba.
Ely, Wm. G., Jr.....Schenectady, N. Y.
Hadley, Theodore H.....Oswego, N. Y.
Knapp, Edwin C.....Syracuse, N. Y.
Lager, Carl A.....Baldwinsville, N. Y.
Ludlow, Wm. Orr.....New York City.
Powell, Emery A.....Aurora, Ill.
Prather, H. B.....Buffalo, N. Y.
Perkins, Thos. C.....Chicago, Ill.
Read, Carlton A.....Boston, Mass.
Schoenleber, John J.....Schenectady, N. Y.
Schriver, Harry T.....New York City.
Swan, James.....Boston, Mass.
Swift, Charles C.....Chicago, Ill.
Vanderhoef, George.....Brooklyn, N. Y.
Watson, Frank.....Brooklyn, N. Y.
Webster, Wm. R., Jr.....Bridgeport, Conn.
Whiteside, John C.....Mt. Vernon, O.
Wilson, Fred'k A.....Boston, Mass.

Juniors, 23.
Total, 84.

The members in attendance were requested to register themselves, and the following names appear upon the record.

Abbott, Wm. L.....Chicago, Ill.
Ackerman, Wm. S.....Durango, Colo.
Alden, Geo. I.....Worcester, Mass.
Aldrich, W. S.....Morgantown, W. Va.
Allison, Robert.....Port Carbon, Pa.
Almond, Thomas R.....Yonkers, N. Y.
Anderson, W. E.....Blacksburg, Va.
Appleton, Thomas.....Chicago, Ill.
Ashley, Geo. T.....Indianapolis, Ind.
Baker, Benjamin (*Honorary Member*).....London, England.
Baker, Chas. Whiting.....New York City.

Baldwin, Bert. L. ..... Cincinnati, O.
Baldwin, Stephen W. ..... New York City.
Ball, Frank H. ..... New York City.
Bancroft, J. Sellers ..... Philadelphia, Pa.
Barnaby, Chas. W. ..... Meadville, Pa.
Barnard, Geo. A. ..... Salem, O.
Barnes, D. L. ..... Chicago, Ill.
Barnes, W. F. ..... Rockford, Ill.
Barr, John H. ..... Ithaca, N. Y.
Barratt, E. G. ..... Chicago, Ill.
Barrus, Geo. H. ..... Boston, Mass.
Bartlett, Geo. B. ..... Chicago, Ill.
Barth, E. C. ..... Chicago, Ill.
Basford, Geo. M. ..... Chicago, Ill.
Bates, Edward P. ..... Syracuse, N. Y.
Beardsley, Arthur ..... Swarthmore, Pa.
Betts, Alfred ..... Wilmington, Del.
Bird, W. W. ..... Cambridgeport, Mass.
Birkinbine, John ..... Philadelphia, Pa.
Bond, Geo. M. ..... Hartford, Conn.
Bonner, Wm. T. ..... Chicago, Ill.
Brush, Chas. B. ..... New York City.
Bryant, Geo. H. ..... Palo Alto, Cal.
Bullock, M. C. ..... Chicago, Ill.
Bull, Storm ..... Madison, Wis.
Butcher, Jos. J. ..... New York City.
Capen, T. W. ..... Chicago, Ill.
Carpenter, R. C. ..... Ithaca, N. Y.
Cary, A. A. ..... New York City.
Chamberlain, P. M. ..... Aurora, Ill.
Chase, Wm. L. ..... Worcester, Mass.
Clarke, Chas. L. ..... New York City.
Clements, Wm. L. ..... Bay City, Mich.
Cloud, Jno. W. ..... Chicago, Ill.
Cogswell, W. B. ..... Syracuse, N. Y.
Cole, J. W. ..... Columbus, O.
Collins, Chas. M. ..... South Bend, Ind.
Conway, Geo. M. ..... Milwaukee, Wis.
Connell, James A. ..... New York City.
Coon, J. S. ..... Atlanta, Ga.
Coxe, Eckley B. (*President*) ..... Drifton, Pa.
Cromwell, J. C. ..... Joliet, Ill.
Davis, D. W. ..... Chicago, Ill.
Davis, E. F. C. ..... Richmond, Va.
Delancey, Darragh ..... Rochester, N. Y.
Denton, Jas. E. ..... Hoboken, N. J.
Dickie, Geo. M. ..... San Francisco, Cal.
Dinckel, Geo., Jr. ..... Jersey City, N. J.
Dingee, W. W. ..... Racine, Wis.
Dixon, Geo. E ..... Chicago, Ill.

Dodge, Wallace H.....Mishawaka, Ind.
Downe, H. S.....Chicago, Ill.
Drummond, D. D.....Chicago, Ill.
Drummond, W. W.....Louisville, Ky.
Drysdale, W. A.....Philadelphia, Pa.
Dunlap, Frank M.....Detroit, Mich.
Durand, Wm. F.....Ithaca, N. Y.
Durfee, W. F.....W. New Brighton, N. Y.
Eilers, Carl E.....Chicago, Ill.
Engel, Louis G.....Brooklyn, N. Y.
Ewart, Wm. D.....Chicago, Ill.
Ewer, R. G.....Natrona, Pa.
Falkenau, Arthur.....Philadelphia, Pa.
Firestone, Joe F.....Columbus, O.
Flather, Jno. J.....Lafayette, Ind.
Forsyth, Wm.....Aurora, Ill.
Foster, Chas. F.....St. Louis, Mo.
Freeman, Jno. R.....Boston, Mass.
Frick, A. O.....Waynesboro, Pa.
Fritz, Jno.....Bethlehem, Pa.
Galloupe, Francis E.....Boston, Mass.
Gibbs, George.....Milwaukee, Wis.
Giddings, C. M.....Sioux City, Ia.
Goss, W. F. M.....Lafayette, Ind.
Griffin, C. L.....Muskegon, Mich.
Guilford, Wm. M.....Lebanon, Pa.
Halsey, F. A.....Sherbrooke, Can.
Hartness, Jas.....Springfield, Vt.
Hazard, Vincent G.....Wilmington, Del.
Henning, Gus. C.....New York City.
Hibbard, H. D.....Highbridge, N. J.
Higgins, M. P.....Worcester, Mass.
Hildreth, R. W.....New York City.
Hill, Warren E.....Brooklyn, N. Y.
Hobart, F. G.....Beloit, Wis.
Holmes, Isaac V.....Beloit, Wis.
Hoppes, J. J.....Springfield, O.
Howe, H. M.....Boston, Mass.
Hugo, T. W.....West Duluth, Minn.
Humphrey, Jno.....Keene, N. H.
Hunt, Alfred E.....Pittsburgh, Pa.
Hunt, C. W.....New York City.
Hunt, R. W.....Chicago, Ill.
Hutton, F. R. (*Secretary*).....New York City.
Ide, A. L.....Springfield, Ill.
Jacobus, D. S.....Hoboken, N. J.
Janson, E. N.....Washington, D. C.
Jewell, C. W.....Beaufort, S. C.
Johnson, E. E.....Chicago, Ill.
Johnson, J. B.....St. Louis, Mo.

Johnson, A. E. ..... Stamford, Conn.
Jones, David P. ..... Redfield, Conn.
Jones, W. Clyde ..... Chicago, Ill.
Kafer, J. C. ..... New York City.
Kent, William ..... New York City.
Kerr, C. V. ..... Fayetteville, Ark.
King, Charles I. ..... Madison, Wis.
Kirkevaag, Peter ..... Youngstown, O.
Landreth, O. H. ..... Nashville, Tenn.
Lane, J. S. ..... Chicago, Ill.
Lanza, Gaetano ..... Boston, Mass.
Le Van, W. B. ..... Philadelphia, Pa.
Lewis, D. J., Jr. ..... Chicago, Ill.
Lewis, J. F. ..... New York City.
Lipe, C. E. ..... Syracuse, N. Y.
Loring, C. H. ..... Brooklyn, N. Y.
Loss, H. V. ..... Philadelphia, Pa.
Low, F. R. ..... New York City.
Lyal, W. L. ..... New York City.
McFarland, W. M. ..... Washington, D. C.
MacDonald, W. R. ..... Chicago, Ill.
Magruder, W. T. ..... Nashville, Tenn.
Manning, C. H. ..... Manchester, N. H.
Mansfield, A. K. ..... Salem, O.
Mason, H. I. ..... Muskegon, Mich.
Matlack, J. R., Jr. ..... Philadelphia, Pa.
Mattice, A. M. ..... Cambridgeport, Mass.
Mattsson, A. G. ..... Detroit, Mich.
May, De Courcy ..... Philadelphia, Pa.
Meier, E. D. ..... New York City.
Melcher, C. W. ..... St. Louis, Mo.
Mellin, C. J. ..... Richmond, Va.
Metcalf, William ..... Pittsburgh, Pa.
Middleton, Harvey ..... Pullman, Ill.
Miller, F. J. ..... New York City.
Moeller, F. ..... Akron, O.
Morava, Wensel ..... Chicago, Ill.
Moreau, Eugene ..... Philadelphia, Pa.
Morgan, C. H. ..... Worcester, Mass.
Morison, George S. ..... Chicago, Ill.
Morse, C. H. ..... Buffalo, N. Y.
Moore, C. A. ..... New York City.
Nagle, A. F. ..... Chicago, Ill.
Nason, C. W. ..... New York City.
Nicholson, W. T. ..... Providence, R. I.
Nordland, Lawrence ..... Medford, Mass.
O'Connell, J. C. ..... Montgomery, Ala.
Owens, R. B ..... Lincoln, Neb.
Parker, C. D. ..... Worcester, Mass.
Parks, E. H. ..... Providence, R. I.

Passel, G. W. ..... Cincinnati, O.
Peck, S. B. ..... Chicago, Ill.
Pike, W. A. ..... Minneapolis, Minn.
Platt, John ..... Riverton, N. J.
Pope, S. I. ..... Chicago, Ill.
Porter, H. F. J. ..... Chicago, Ill.
Prentice, L. H. ..... Chicago, Ill.
Pratt, F. C ..... Hartford, Conn.
Quimby, W. E. ..... New York City.
Quint, A. D. ..... Hartford, Conn.
Raynal, A. H. ..... Elizabeth, N. J.
Reber, L. E. ..... State College, Pa.
Reuleaux, Francis (*Honorary Member*). ..... Berlin, Germany.
Ridgway, J. T. ..... Clinton, N. J.
Rites, F. M. ..... Pittsburgh, Pa.
Roberts, William ..... Waltham, Mass.
Robinson, J. M. ..... New York City.
Robinson, S. W. ..... Columbus, O.
Roelker, H. B. ..... New York City.
Rogers, W. A. ..... Waterville, Me.
Roney, W. R. ..... Boston, Mass.
Rumely, W. N. ..... La Porte, Ind.
Russel, W. S. ..... Detroit, Mich.
Samuels, J. H. ..... Moline, Ill.
Sanders, Newell ..... Chattanooga, Tenn.
Sanguinetti, P. A. ..... Chicago, Ill.
Sargent, C. E. ..... Chicago, Ill.
Scheffler, F. A. ..... New York City.
Sederholm, E. T. ..... Chicago, Ill.
Seymour, J. A. ..... Auburn, N. Y.
Sinclair, G. M. ..... Philadelphia, Pa.
Smith, H. W. ..... Elizabeth, N. J.
Smith, Jesse M. ..... Detroit, Mich.
Spangler, H. W. ..... Philadelphia, Pa.
Spencer, E. J. ..... Chicago, Ill.
Spilsbury, E. G. ..... Trenton, N. J.
Sprague, W. W. ..... Chicago, Ill.
Stevens, E. A. ..... Hoboken, N. J.
Stevenson, A. A. ..... Philadelphia, Pa.
Stiles, N. C. ..... Middletown, Conn.
Strale, Allan ..... Chicago, Ill.
Stratton, E. P. ..... New York City.
Street, C. F. ..... Chicago, Ill.
Suplee, H. H. ..... Stamford, Conn.
Swain, George F. ..... Boston, Mass.
Sweeney, J. M. ..... Wheeling, W. Va.
Sweet, John E. ..... Syracuse, N. Y.
Taylor, J. T. ..... New York City.
Thomas, E. G ..... Butte, Mont.
Thompson, E. B. ..... Chicago, Ill.

Thompson, E. P.	New York City.
Thompson, E. W.	Atlanta, Ga.
Thorp, Geo. G.	Chicago, Ill.
Thurston, R. H.	Ithaca, N. Y.
Torrance, K.	Chicago, Ill.
Tompkins, S.	Charlottesville, Va.
Towle, W. M.	State College, Pa.
Upson, L. A.	Thompsonville, Conn.
Varney, W. W.	Baltimore, Md.
Veeder, C. H.	Lynn, Mass.
Wagner, John R.	Drifton, Pa.
Ware, J. A.	Worcester, Mass.
Weaver, S. B.	Chicago, Ill.
Webster, H.	Chicago, Ill.
Webster, John	Boston, Mass.
Weeks, G. W.	Clinton, Mass.
Wellman, S. T.	Thurlow, Pa.
Whaley, W. B. S.	Columbia, S. C.
Whitaker, H. E.	Detroit, Mich.
Whitehead, G. E.	Providence, R. I.
Whitney, B. D.	Winchendon, Mass.
Whitney, W. M.	Winchendon, Mass.
Whittemore, D. J.	Chicago, Ill.
Whittier, Charles	Boston, Mass.
Wiley, W. H. (*Treasurer*)	New York City.
Wood, De Volson	Hoboken, N. J.
Woodbury, C. J. H.	Boston, Mass.

Total, 283.

There were also registered, as guests of the Society and delegates to the Congress, the following:

W. Ripper	Sheffield, England.
Thomas H. Brigg	Bradford, England.
H. Kidd	Sydney, Australia.
Paul Debray	Paris, France.
Baron Guinette de Rochemont	Paris, France.
Lucien Périssé	Paris, France.
A. Flamant	Paris, France.
M. S. Carrière	Paris, France.
G. Rigeaux	Charleville, France.
Alfred Vanderstegen	Ghent, Belgium.
A. von Borries	Hannover, Germany.
Fr. Freytag	Chemnitz, Saxony.
Edward Günther	Madgeburg, Germany.
Hans König	Vienna, Austria.
Hermann Ritter von Littron	Vienna, Austria.
W. Voit	Berlin, Germany.
Adalbert Stradal	Vienna, Austria.
A. Weber Ebenhof	Brunn, Austria.

Carl Wilhelm	Berlin, Germany.
A. Schrey	Berlin, Germany.
B. Nebel	Berlin, Germany.
Ed. Schroeder	Berlin, Germany.
Haas Louis Schiken	Broumbergh, Germany.
Kuno Thurnauer	Nuremburg, Bavaria.
Theodor Voss	Magdeburg, Germany.
P. C. Ludwig Weber	Frankfort, Germany.
Josef Pechan	Vienna, Austria.
Rud. Franke	Hannover, Germany.
Max. Gary	Berlin, Germany.
A. Fitzner	Laurakutte, Germany.
W. Hartmann	Berlin, Germany.
Reinhard Hornell	Stockholm, Sweden.
J. L. Sebenius	Stockholm, Sweden.
Charles E. Bratt	Stockholm, Sweden.
Otto G. Enger	Horten, Norway.
T. Yoshida	Tokyo, Japan.
Alfred Nyberg	St. Petersburgh, Russia.
Nicolas Vornosenky	St. Petersburgh, Russia.
Alex. Krupsay	St. Petersburgh, Russia.
Professor Busley	Kiel, Russia.
E. J. Chibas	Colon, Colombia, S. A.
Matlausch Tivadar	Budapest, Hungary.
Prof. A. Martens	Berlin, Germany.

Many others, both among foreign delegates and American attendants, failed to register themselves.

After certain announcements this preliminary session adjourned for the excursion tendered for the afternoon.

While the Society had assumed for the Executive Committee of the Associated Societies the burden of conducting its share of the Congress work, it had not appeared that for this reason it was necessary for the members of the Society to forego expected features of its usual conventions, which would not interfere with the work or success of the Congress, and which would supply some of the social and professional opportunities which otherwise would be lacking at such a meeting. By the courteous energy and interest of an active member of the Society, Mr. H. F. J. Porter, of Chicago, a most satisfactory programme of opportunity at the grounds of the Exposition had been arranged for the afternoon of Monday, following the adjournment of the Congress for that day. These invitations, procured originally for the Society of Mechanical Engineers and its guests, by Mr. Porter and through his friends, were by his liberality and theirs extended to members of all the sister engineering societies represented at the Con-

gress, so that the party became a very large one of over five hundred, under the auspices of the original hosts.

The programme was to have begun by a trip from the Van Buren Street wharf to the Exposition pier, on the whale-back steamer "Christopher Columbus," the party being the guests of the steamer company. By reason of the high wind which had arisen, it did not seem wise to risk landing at the exposed and unsuitable pier at the Exposition, and the party was therefore taken out by a special train on the Illinois Central Railway, tendered by its management. At the grounds, the military band organized by the Association of Exhibitors at the Exposition was put at the head of the party by Major J. C. Pangbourne, and conducted it across the grounds to the pier for a ride upon the movable sidewalk, and an opportunity to inspect its working under the guidance of its originator, Mr. Max E. Schmidt. Thence the party was conveyed to the Music Hall, where the engineers of the Exposition were in attendance with the drawings of the drainage, grading, transportation, and power systems on the grounds, and exhibited them after salutatory addresses from Mr. Porter of the Mechanical Department, Chief Burnham of the Administration, and a reply by President Coxe of the Society.

The party was then convened at the Krupp pavilion, from which for the time the public was excluded; and at this point, after a greeting from Herr Richter in charge of this exhibit, and brief remarks by Messrs. Porter and Coxe, the immense rifles of the exhibit were put through an exhibition drill to demonstrate their manœuvering power, and a special opportunity was allowed to examine the remarkable showing in this building. A light lunch was also spread, and the band had been assembled in the gallery. At the close of this most appreciated exhibition, the party was conveyed by a special train of the Intramural Railway to the Power House operated by the General Electric Co. for the uses of the Exposition, where it was the guest of Lieut. E. J. Spencer, member of the Society. Taking again the electric railway, the complete circuit of the grounds was made, ending at the Pumping Station of the Exposition with an inspection of the Worthington Pumping Plant. Here, again, the band made a concert of the exhibition. In the evening, by the same indefatigable attention, arrangements had been made for complimentary visits to a number of points of interest, to which the party should be admitted

by an exhibition of the Society's badges. This resulted in a very general use during the week of the Congress of the characteristic button or souvenir badge used by this Society. The places showing this courtesy were: The Ferris Wheel, the Ice Railway, the Military Tournament, the Electric Launch Route, and others. The trip over the whale-back steamer and to the Two Mile Crib and water-works tunnel, which was deferred on account of the weather, was postponed till Thursday afternoon, when by the courtesy of Messrs. Lydon and Drews, the contractors, trips by boat were made from the Exposition pier out to the designated point.

Second Day, Tuesday, August 1st.

With this session, convened at 10 A.M. in Hall No. VII. of the Memorial Art Palace (where all sessions for papers were held), the professional work of the Congress opened. The first business was the presentation of the Report of Progress by the Committee of the Society upon Standard Methods of Testing Materials, by its Secretary, Mr. Gus. C. Henning, who had attended, as delegate from this Society, the Conference of the German Union at Vienna in May. The Report and its Appendix are presented separately as papers of the meeting. In its discussion, the following took place:

*Mr. Gustavus C. Henning.**—It is the usual custom of the Committee of this Society on Standard Methods of Test and Testing Materials, to make a statement of the work which it has done, but all we have to offer now is what others have done. These others are the most prominent engineers and manufacturers in testing materials and standardizing methods of tests. With this in view, the committee has drawn up a short report, with an appendix, which there was not time to put in print because the manuscript came here only three weeks ago, the Vienna conference which we report having occurred during the last week in May. Hence, since the corrections of the stenographic report of the proceedings had to be returned to the German editor and then sent back here, there was very little time left to put the matter in the hands of the American printer. It is, however, now in such shape that it can immediately be distributed when printed. The Committee offers herewith its report, which, with

* Secretary of the Committee, and its Reporter.

its appendices, will be printed as one of the papers of the meeting, and append to it the following resolutions:

Whereas, The American Society of Mechanical Engineers considers it to be of the greatest importance that its members be constantly informed of the latest developments and additions to methods of testing materials; and,

Whereas, This can only become a fact by the constant interchange of opinions by engineers and manufacturers of all countries: therefore,

Be it Resolved, That the American Society of Mechanical Engineers urge the inauguration of International Conferences for the Unification of Methods of Testing, and also urge our Government to take cognizance of such Conferences by sending duly accredited representatives.

Prof. Paul Debray, of Paris, is present as the official representative of the government commission of France, appointed at the World's Exposition in Paris, in 1889, with a view of furthering, urging, and helping on the establishment of an international commission having these same objects in view as are sought by our committee. Prof. Debray has asked me to read the following paper, because he thinks he could not make himself clearly understood by all.

"*Prof. Paul Debray.**—All those who, in various capacities, have to deal with this question have already admitted the importance, theoretical as well as practical, of adopting uniform methods for the various elements of constructions of a public or private character.

Data which appear identical in numerical results of resistance or elongation may, in reality, apply to very different qualities of the tested materials, according to the degree of care bestowed on the tests, to the dimensions and forms of the samples tested, or even according to the apparatus and methods used.

The testing methods cannot, obviously, remain always the same; they must improve with our growing knowledge of the properties of the materials used, with the improvements in the production thereof, with the discovery of new materials, etc.

It is plain, also, that for a given kind of materials, the conditions of tests under which they are to be made will vary somewhat with the countries in which they are made, with the various administrative departments in the same country, or even with the specifications prepared under the same administration, when the materials of construction are to be employed under various local conditions.

* Chief Engineer of Ponts et Chaussees in France, Professor and Director of the Laboratories at the School of Ponts et Chaussees of Paris, General Secretary of the French Commission in charge of tests of materials of construction.

It is undeniable, however, that it would be eminently useful, as well to those who manufacture the materials of construction as to the contractors who use them, and to the public bodies and private persons for whom the work is executed, to determine the present status of our knowledge as to the properties of materials of construction and to the testing methods to be used; also to define, in a manner sufficiently authoritative to command everybody's approval, for the present or for a more or less immediate future, the forms of tests and the units to be adopted as a basis of comparison.

It is under such conditions that two previous International Congresses, held in Paris at the time of the Exposition of 1889, expressed some wishes to that effect: one, the International Congress on Methods of Construction, recommended that rules should be established which, in all countries, would be uniformly admitted, for the control and acceptance of limes and cements; the other, the Congress of Applied Mechanics, especially in view of the tests of metals, expressed the wish that the French Government take the initiative in asking other nations to create an International Commission, whose mission would be to select common units for the expression of the results of all tests, and to introduce a certain amount of uniformity in testing methods.

With the advice of those of his colleagues interested in these matters, the French Secretary of Public Works, in a report dated November 9, 1891, proposed to the President of the Republic to create at first a National Commission for the purpose of establishing, for France alone, a uniform system of units of measures for the tests of materials of construction.

That commission, presided over by Mr. Picard, Inspector-General of Ponts et Chaussees, Section President of the Council of State, began its labors immediately after its appointment.

In 1892 the Congress of Railroads convened at St. Petersburg, with the knowledge of the progress made by the French commission just mentioned, reiterated the wish expressed by the International Congress of 1889.

We have the honor to offer to-day to the Engineering Congress of Chicago the results of the labors of the French National Commission after their first and very laborious session.

These results include especially two general reports, one relative to metals, the other to cements and mortars. The conclusions proposed in the above reports were adopted by the commission at its meeting of May 12, 1893.

As can be seen by a cursory reading of these general reports, and of the special reports annexed thereto, the French commission has endeavored to give due weight to the results achieved, not only in France but in all other countries.

We must especially call the attention of those interested in these questions to the excellent bibliographic notes prepared by Mr. Cordier, Librarian of the School of Ponts et Chaussees of Paris, in collaboration with the members of the commission and with the scientists with whom we have been for a long time in correspondence in all countries of the world. At any rate, these bibliographic notes will be very useful to easily trace the results of anterior work on the questions at hand.

In conclusion, allow me to express the earnest hope that the sections of the Engineering Congress of Chicago, which are interested in these matters, will confirm the resolutions passed in the International Congress of 1889, for the establishment of an international understanding in regard to the means to be adopted to bring a world-wide unification of methods for the tests of materials of construction."

The results of the conference at Vienna I have here in German pamphlets; and while I have only fifty copies, those who can use them are welcome to them, though of course there are too few to go around. I should like to say that Professor Martens, director of the Royal Testing Laboratory at Berlin, is present, and he has been delegated to urge the adoption of international conferences on the subject.

Professor Martens,* of Berlin, spoke in German, his remarks being translated as follows by the Chairman:

The first notion of an international and uniform method of test for materials, and that which gave it a start in Germany, was a correspondence from Professor Egleston of this Society; the professor is not sure what committee he represented, but that was the origin of the movement in Germany. Professor Martens also stated that the French people had coöperated with them, and that Professor Debray was a delegate to the conference.

Mr. Henning.—I would state that Dr. Egleston made the proposition referred to, in 1884, originally, upon his appointment as Chairman of the Committee of this Society by the American Society of Mechanical Engineers.

The resolutions of the Report of the Committee were then adopted.

* For full text of remarks of Professor Martens see page 1260 of this volume.

Mr. S. W. Baldwin.—To give effect to this action I would offer the following—and this is a resolution offered not by the American Society of Mechanical Engineers, but by the Engineering Congress:

Resolved, That, in view of the great importance of a uniform international system of testing materials, this International Congress of Engineers requests the Society of Mechanical Engineers to take such measures as will effectively further the object desired.

This resolution was unanimously adopted.

At the conclusion of these matters, the papers assigned for the session were taken up and read and discussed.

Prof. W. F. M. Goss' paper, "Tests of the Locomotive at the Laboratory of Purdue University," had been read as part of the Report of the Committee on Standard Tests of Locomotive Efficiency, and discussed by Messrs. Denton, Sir Benjamin Baker, and Gibbs, but the other locomotive papers were read in due course. M. A. Mallet, of Paris, France, presented one entitled "Locomotives operated by Total Adhesion on Curves of Small Radius;" Mr. A. von Borries, of Hanover, Germany, presented one upon "Compound Locomotives," discussed by Messrs. Gibbs, Cooper, Hibbard, and Suplee; and Mr. Albert Schneider, of Brunswick, Germany, presented one entitled "Experience in the Working of Rack-Railways," discussed by Messrs. von Borries, Hildenbrand, Suplee, and Coxe.

The session concluded by returning to the presentation of the final report of the Society's Committee on a Standard Method of Conducting Locomotive Tests, presented by Mr. William Forsyth, discussed by Messrs. Lanza, Gibbs, and Meier; and the following preamble and resolution were offered by Mr. Gibbs:

Whereas, The report of the Committee on a Standard Code for Locomotive Tests has recognized the value and importance of a shop test of locomotives, such as is available with apparatus at Purdue University; and

Whereas, The authorities of the University are willing to put their apparatus at the disposal of a joint Committee from the Society and from the American Railway Master Mechanics' Association, if the expenses of such tests are forthcoming; and

Whereas, The Master Mechanics' Association has already appointed a Committee for prosecuting such an investigation: therefore, be it

Resolved, That a Committee be appointed to coöperate with the Committee of the American Railway Master Mechanics' Association to carry out such an investigation at Purdue University, to the extent of testing and reporting the performance of one simple and one compound locomotive.

This resolution was put and carried.

Mr. Carleton W. Nason presented for the Society's Committee on Standard Diameters for Flanges of Valves, etc., the following report:

Mr. Carleton W. Nason.—It will be remembered by those who were at the New York meeting of 1892, that the Committee on Flanges submitted a scale which appeared to meet the general demand without necessitating considerable or costly alterations of sizes now in use. At that time a request was made by the Committee that the scale should be criticised and investigated with the view to its possible improvement. The remarks were comparatively few, and the scale was therefore allowed to remain as prepared. During the spring it was learned that a Committee had been appointed for similar work by the Master Steam and Hot Water Fitters' Association, who were also desirous of establishing a standard scale; and this Committee has been in communication with them, with the result that their Committee approved our scale as a whole; and the convention of the Association, which was held in this city in May, adopted it, their secretary and members promising as far as possible to induce manufacturers to adopt that scale. After they adjourned, and during the past month, the Committee of this Society sent out a circular to the manufacturers of flange goods, of which the following is a copy:

AMERICAN SOCIETY MECHANICAL ENGINEERS,
12 West Thirty-first Street,
New York City.

Subject: Flange Standardization.

14*th July*, 1893.

Dear Sir: At a meeting of the American Society of Mechanical Engineers, held in this city, the Committee on Flange Standardization, appointed by the Board of Management, submitted a report for criticism upon the question, which comprised the result of their work up to that time, including a list of suggested sizes and a scale from which they were made, plotted upon section paper.

It being learned that a Committee for similar work had been appointed by the Master Steam and Hot Water Fitters' Association, it was thought advisable to defer further conference with manufacturers of goods having flanges, until such time as the Master Steam and Hot Water Fitters' Committee had made their own report, or it had been acted on by their Association.

This has just been accomplished at the Annual Convention of the Association, held in Chicago, in June, where their Committee reported that after a careful investigation of the subject it was their conclusion that the standard which had previously been submitted by the A. S. M. E. Committee met with their entire

approval, and they therefore recommended that the same standard be adopted by their Association. A resolution to this effect was immediately carried by unanimous vote. The Committee being still retained, they were instructed to communicate with manufacturers interested, with a view to inducing the latter wherever practicable to adopt the proposed standard as applied to all cast-iron flanged products made by them.

A copy of the A. S. M. E. Report, including the proposed standards, is enclosed herewith, and its Committee would ask for your criticism of the scale as submitted. If as a whole it meets your approval, and you would be willing to so modify your patterns as to follow it provided it is adopted by all of the larger manufacturers, or if you wholly object to it, labor of correspondence may be saved by returning the postal card with your signature. If, however, it is your opinion that the dimensions may be changed without conflicting with the many interests involved, and the whole list of varying standards harmonized by further modification, it is hoped that you will write fully upon the subject.

As the next convention of the A. S. M. E. occurs at Chicago, beginning July 31st, and this committee is desirous of reporting to the Society at that time as to the expressions of opinion by manufacturers on the subject, it is urged that you will aid the Committee in their work by communicating with them if possible prior to the above date.

Replies may be sent either to Prof. F. R. Hutton, Sec'y, at No. 12 West 31st Street, or to the undersigned at 71 Beekman Street, New York City.

Respectfully yours,

CARLETON W. NASON,

Chairman Committee on Flange Standardization.

The postal card referred to above in the fourth paragraph was as follows:

.....

.....1893.

To Committee on Flange Standardization:

GENTLEMEN:

As a whole I do.....approve of the proposed
or not

Flange Standard, as submitted, and would.....be
or not

willing to adapt flanges made by me.....to it, if
or us

adopted by all the larger manufacturers.

Very truly yours,

.....

The replies up to this date have not been very large; they number about thirty in all, and of that number there is but one concern which unqualifiedly rejects it without giving any reason for so doing. The Committee would again at this time like to hear

from any members present as to suggestions about their future work, or about any modifications in the scale which may seem desirable. The report that was made at the November meeting in New York is here for distribution to this end.

After the presentation of this report the session adjourned.

Third Day, Wednesday, August 2d.

The papers of this session were by Prof. Gustav Herrmann, of Aachen, Germany, honorary member of the Society, on "The Working of Centrifugal Machinery," discussed by Mr. Ball; on "The Removal of Dust from Workshops," by R. Kohfal, of Hamburg, Germany, discussed by Messrs. Vanderstegen, of Ghent, Belgium, and by Mr. T. Clarkson, of England; on "The Taxameter, or Fare Indicator," by H. Pieper, of Hamburg, Germany; on "Apparatus for Metering Steam," by Franz Seiler, of Mannheim, Germany; on "Improvements in the Art of Cable-making," by Emil Guilleaume, of Mulheim, Germany; on "The Measuring of Water and the Schinzel Water Meter," by F. Lux, of Ludwigshafen, Germany. Mr. W. F. Durfee, of New York, read in full, as the concluding paper, "The Interchangeable System of Manufacture," and the session adjourned.

In the evening a reception was held at the Engineering Headquarters of the Associated Engineering Societies, at No. 10 Van Buren Street, which was enjoyed by many.

Fourth Day, Thursday, August 3d.

This day was mainly devoted to steam engineering. Prof. V. Dwelshauvers-Dery, of Liège, Belgium, honorary member of the Society, presented "A Contribution to the Theory of the Steam Engine;" Mr. Charles T. Porter, of New Jersey, also an honorary member, presented a paper on "The Limitation of Engine Speed," discussed by Messrs. Mansfield, Porter, and Vanderstegen. The other papers were on "Compression as a Factor in Steam Engine Economy," by F. H. Ball, discussed by Messrs. Mansfield, Jacobus, Barr, and Sederholm; on "The Performance of a Triple Expansion Pumping Engine with and without Jackets," discussed by Messrs. Ball, Jacobus, Alden, Mattice, Kent, and Barrus; on "The Performance of Street Railway Power Plants," by Messrs. Wm. A. Pike and T. W. Hugo, discussed by Messrs. Barrus, Lockwood, Jesse M. Smith, Scheffler, Aldrich, Nason, Sederholm, and Reist; on "An Evaporative Surface Condenser," by the late Prof. Jas. H.

Fitts, who had lost his life in a railway accident while on his way to the meeting. Suitable remarks were made by Mr. Aldrich and others, and a memorial note by the brother of Professor Fitts was read to the meeting. The two following papers were by Geo. H. Barrus on "A Coal Calorimeter," discussed by Messrs. Cary, Jesse M. Smith, Kent, and Coxe; and the other on "Anhydrous Ammonia Gas as a Motive Power," by T. W. M. Draper, discussed by Messrs. Wood and Kent. The session then adjourned.

After luncheon, the trip via the whale-back steamer "Christopher Columbus" was made, to convey the members of the various sections of the Congress out to the Exposition pier, and there boats of the contractors Messrs. Lydon and Drews conveyed those specially interested out to the Two-mile Crib of the Water Works Extension, and an opportunity was given for a descent into the tunnel and to the air-lock. This had been a part of the excursion tendered to the Society originally for Monday, but deferred reason of unfavorable wind on that afternoon.

Fifth Day, Friday, August 4th.

The final session for the reading of papers embraced papers on a "General Engineering Classification and Index," discussed by Messrs. Baldwin and Bancroft; on "Haulage by Horses," by Thomas H. Brigg, of Bradford, England, discussed by Professors Thurston, Hutton, and Hele-Shaw, and by Mr. John G. Shortall, President of the Illinois Humane Society, present by invitation. Mr. Shortall presented the following resolution:

Resolved, That this meeting request the author of this paper, at his own convenience, in the near future, to repeat this address, together with such matter added thereto as he has not been able from lack of time now to present, with the view of promoting the benefit that is contemplated to animals in the scientific proposition underlying this paper.

This resolution was duly seconded and carried.

Mr. A. Sorge, of Munich, presented on behalf of Prof. C. Linde his paper on the "Refrigerating Machine of To-day," which was discussed by Professor Jacobus; and the discussion resulted in the following motion in its amended form:

Resolved, That it be referred to the Council of the American Society of Mechanical Engineers to appoint a committee to consider and decide upon rules according to which tests of refrigerating machines are to be carried on, and in doing this to act in conjunction with the Polytechnic Union of Munich.

This motion, duly seconded, was carried.

The paper by F. H. Daniels on "Wire Rod Rolling Mills, and their Development in America," was followed by that of Prof. R. H. Thurston on "Technical Education in the United States," discussed by Messrs. Kent, Porter, Lanza, Cole, Durfee, Alden, and Coxe. Mr. Porter presented in his remarks the following resolutions, which were duly seconded and carried:

Resolved, That it be referred to the Council of the American Society of Mechanical Engineers to consider the advisability of recommending to educational institutions a uniform system of technical education, and that it endeavor, in connection with the American Society of Civil Engineers, the American Society of Mining Engineers, the American Society of Electrical Engineers, and the Canadian Society of Civil Engineers, and with such other organizations as may be competent, to carry out such a uniform system as is deemed desirable.

Also, *Resolved*, That the Council be requested to consider the advisability of recommending that technical institutions give the degree of Bachelor of Engineering only, and of establishing a body which would have the authority to give the final title of Engineer, and that it endeavor, in connection with the above-mentioned societies, to carry out such a programme.

The final paper by A. Huet, of Delft, Holland, was entitled "Notes on the Drainage Machinery of the Netherlands," and was accompanied by a series of pamphlets in the Dutch language in further illustration of the topic, which are a gift of the author to the library of the Society. The session then adjourned.

An opportunity was given in the afternoon for a visit to the folding bridge across the Illinois River at Canal Street, the steamer "Burroughs" conveying the party.

Sixth Day, Saturday, August 5th.

The entire Congress met in joint session in the large hall for a final session and for adjournment. The chairmen of the several sections or representative delegates gave brief reports of work done, and others also spoke of the satisfactory character of the Congress as an undertaking by the profession of engineering on behalf of the nations or countries represented. At the close of these remarks, the chairman, Mr. Octave Chanute, announced the Congress adjourned.

Letters of thanks were sent by direction of the Council after

the close of the Congress to the following parties, who had been hosts of the party or who had been the means of securing courtesies for the members of the Society in Chicago.

The Honorable Council of Administration.
The World's Fair Steamship Co.
The Pier Movable Sidewalk Co.
The International Exhibitors' Association.
The Ferris Wheel Co.
The De la Vergne Refrigerating Co.
The Electric Launch and Navigation Co.
The World's Fair Steam Launch Co.
The Otis Elevator Co.
The Military Tournament (Ltd.).
E. J. Spencer, General Electric Co.
H. R. Worthington.
Messrs. Lydon & Drews, Contractors for Crib.
A. Lauter, Krupp Pavilion.
D. H. Burnham, Director of Works.
H. F. J. Porter, Assistant Chief Department of Machinery.
Exhibitors of Department Mines and Mining, Chief Skiff and staff.

DXXVII.*

CONTRIBUTION TO THE THEORY OF THE STEAM-ENGINE.

BY PROF. V. DWELSHAUVERS-DERY, LIÈGE, BELGIUM.

(Honorary member of the Society.)

It was first enunciated and proven by M. Hirn that it is not possible to-day to formulate a *generic theory* for each type of steam-engine. This is not to say that it is impossible to go further than the general formula of M. Carnot, which applies equally well to all heat-engines, inasmuch as, by a parity of reasoning, it might be supposed useless to push investigation further for hydraulic motors than the formula $W = PH$. This formula presupposes conditions of operation which are absolutely incapable of being realized, and for these reasons: First, because it demands that the resistance at every instant be in exact equilibrium with the motor weight; and, second, that no part of the mass of water is lost either by leakage or premature discharge from the bucket.

The cycle of Carnot supposes, in a similar way, conditions which cannot be realized, and especially that its operations should be reversible. This brings about two conditions which are analogous to the foregoing: First, that the resistance against the piston should be at each instant equal to the elastic tension of the fluid; second, that no part of the heat should be lost either by escape through the metal or by premature discharge.

The perfect cycle is so far remote from the daily observed conditions, that it is not called on to render great service in practice any more for machines acting by weight than for heat-engines. For hydraulic motors it has been found convenient to make certain hypotheses plausible enough, on which generic theories could be based, in order to deduce from them the conditions of the maximum effect or the means of increasing the efficiency. In spite of the fact that the results of these formulas have to

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

be corrected by coefficients sometimes enormous, furnished by practice, they are generally held as of real use. Why should it be otherwise with heat-engines? There can be established equally well for the different heat-engines, not generic theories but one general formula giving the maximum of work to be obtained for a given expense of heat or steam, whatever may be the type of machine employed. This formula, in a different way from that of the perfect cycle, would take account of the imperfections of the cycle which are common to all steam-motors, but would not take account of the action of the metal walls, because it is this very action which, according to M. Hirn, forms the insurmountable obstacle in the way of the establishment of a generic theory. It is this topic which will be discussed here.

Outside of the thermal action of the cylinder walls, the losses common to all types of steam-engines, and which form about a third of the perfect efficiency of the Carnot engine, are due to breaks in the cycle, which may be enumerated as follows : First, a lessening of the pressure at admission ; second, an excess at release ; third, an incomplete expansion ; fourth, a too high back pressure during the exhaust ; fifth, no adiabatic compression ; sixth, the exhaust of the steam at each stroke and the restoration of an equal weight of cold water into the boiler where its temperature has to be raised up to that of saturation by means of heat produced in the furnace ; and, finally, a certain velocity necessary, because in order to produce a given horse-power the machine must repeat its closed cycle a definite number of times per minute.

It will be convenient, according to the conception of the writer, to compare to the ideal cycle of the real machine, the performance of steam-engines where the wasteful action of the metallic cylinder walls exists in fact. For each type of engine operating in given conditions, experience can furnish the coefficients of reduction, as has been already done in the matter of water-wheels. It must be said, in passing, that here the experiments are more delicate and could never be conducted to a conclusive result except in laboratories provided with engines capable of being so modified that they can be run under conditions causing a variation only of that element of which the economic influence is to be studied while all the other elements remain unchanged.

In order to obtain a desired horse-power, there must pass a certain weight of fluid through the engine per minute, and hence it must have a certain velocity. From this, losses of kinetic energy follow, which are important in water-wheels by reason of the great density of water, but are without importance on the other hand in steam-engines. Thence in the first type of motors the essential question is to determine that velocity which produces the minimum loss. Thus for each type of wheels a fixed velocity was found. For the Sagebien breast-wheel, the efficiency rises while the velocity decreases, and this latter has no other limit than zero. The question of velocity corresponding to the maximum efficiency for steam-engines, apart from the action of the cylinder walls, has hardly been discussed except by De Pambour, who reaches the same conclusion as for the Sagebien wheel. This conclusion is reversed when action of the walls is considered, and the experiments of Williams prove that these high velocities are favorable to efficiency.

Apart from the action of the walls, the main effect of high speed is to increase the lessening of pressure at admission and the excess during exhaust; but the lessening at admission depends, besides, on local conditions so variable that they will remain unaccounted for in the formula of the ideal cycle of real machines. As to the excess at exhaust, it will be figured at what may be considered its minimum—a thousand kilograms to the square metre (1.4 lbs. per square inch)—a figure which, so far as known, has never been reached, the ordinary back pressure averaging generally about 1,500 kilos. Under these conditions, it will not be necessary to take account of the speed of the engine. It may be admitted, then, that during the admission to the cylinder the pressure of the steam is constant and equal to p_0, which is equal to that of the boiler, so that for each kilogram of steam used the boiler furnishes r_0 units of heat through the cylinder, r_0 being the total latent heat at the pressure p_0. The work during the admission will then be equal to $p_0 u_0$ kilogrammetres, equivalent to $A p_0 u_0$ units of heat. The latter u_0 denotes the volume generated by the piston during the vaporization.

It will be supposed that there is no other clearance space than that occupied by the kilo of saturated water at the pressure p_0, which may be called σ_0. Hence it follows that the volume occu-

pied by the steam at the end of the admission will be $\sigma_0 + u_0 = v_0$. The dryness fraction x_0 is at this instant equal to unity.

After the period of vaporization at constant pressure comes that of an adiabatic expansion carried until the volume occupied by the steam v_1 is equal to nv_0, n being the degree of expansion. During the expansion the dryness fraction (quality) of steam has fallen to x_1, and the pressure to p_1, so that we have

$$r_1 = nv_0 = \sigma_1 + x_1 u_1 ;$$

the final quality x_1, and the final pressure p_1, can be calculated from steam tables and from the known law of adiabatic expansion. This law is

$$\varphi_0 + \frac{x_0 r_0}{T_0} = \varphi_1 + \frac{x_1 r_1}{T_1} ;$$

or,

$$\varphi_0 + \frac{r_0}{T_0} = \varphi_1 + \frac{x_1 r_1}{T_1} . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

If q is the heat of saturated water per kilogram, we have

$$\varphi = \int_0^t \frac{dq}{T},$$

an expression in which T is the absolute temperature corresponding to $t^0 C$.

In the tables published by M. Deruyts, an assistant of the writer, the values for φ and for $\frac{r}{T}$ are given with respect to pressures, which permits equation (d) to be solved with respect to x_1 by means of systematic interpolations.

If the internal latent heat of one kilogram of saturated steam be denoted by ρ, and that of a kilogram of a mixture whose quality is x be designated by U, there will result, in general,

$$U = q + x\rho ;$$

and at the two ends of expansion,

$$U_0 = q_0 + \rho_0,$$

and

$$U_1 = q_1 + x_1 \rho_1.$$

Since the expansion is adiabatic, the work of expansion is equal to $U_0 - U_1$; whence,

$$A W_d = U_0 - U_1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d')$$

On the return stroke it will be assumed that the back pressure p' is constant and equal to 1,000 kilograms to the square metre, and the volume generated by the piston is $x_1 u_1$. The negative work done is therefore $p' x_1 u_1$ kilogrammetres, which is equivalent to

$$A W_e = A p' x_1 u_1.$$

From this it would appear that the total work W kilogrammetres performed for each kilogram of steam used is equivalent to

$$A W = A p_0 u_0 + (U_0 - U_1) - A p' x_1 u_1. \quad . \quad . \quad . \quad (1)$$

From this is immediately deduced the necessary consumption of steam to obtain one horse-power of work per hour, since a horse-power per hour represents 270,000 kilogrammetres. The weight of steam used per horse-power per hour will be equal to

$$\frac{270{,}000}{p_0 u_0 + \dfrac{U_0 - U_1}{A} - p' x_1 u_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It will be convenient to determine the maximum efficiency, which is that of the ideal practical cycle; or, in other words, the relation between the heat converted into work and the quantity of heat expended in order to create the kilogram of steam. It is economical to feed the boiler from the hot well, which has a mean temperature of 35° C.; the heat of a kilogram of water at this temperature, denoted by q', is 35.037. This water must be raised in the boiler to the temperature t_0, which demands $q_0 - q'$ heat-units. The total expense of heat is made up, then, of r_0 and of $q_0 - q'$; or,

$$q_0 - q' + r_0 = \lambda_0 - q',$$

the total heat of the kilogram of steam being denoted by the symbol λ; whence the efficiency in question is

$$\frac{A p_0 u_0 + (U_0 - U_1) - A p' x_1 u_1}{\lambda_0 - q'} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It is proposed to modify the exact formulas (d), (d'), (1), (2), and (3) in order to make them more easy to use. They will then no longer be anything further than approximations, but having a degree of approximation which will in nowise affect their practical utility. Instead of the law of adiabatic expansion (d), the following will be substituted:

$$\frac{p_0}{p_1} = \left(\frac{v_1}{v_0}\right)^{1.13} = n^{1.13}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (D)$$

whence the work W_d during the expansion will be

$$W_d = \frac{p_0 v_0}{0.13}\left(1 - \frac{1}{n^{0.13}}\right). \quad . \quad . \quad . \quad . \quad . \quad (D')$$

It now remains to justify these latter formulas. This will be done by exhibiting the method by which they have been reached. Selecting the initial pressure p_0 very high, equal to nearly ten atmospheres, or 100,000 kilograms per square metre, there have been sought the work (1); the consumption per horse-power per hour (2); and the efficiency (3) for degrees of expansion varying between one and twenty at least. It must be remarked that the calculations become very complicated if the degree of expansion is made the starting point and if the terminal pressure is left among the unknown quantities. It is better to assume the terminal pressure p_1 and to calculate the final volume $\sigma_1 + x_1 u_1$, thus determining the degree of expansion. This procedure has here been followed. Successive values have been given to p_1 from 100,000 to 10,000 by steps of 10,000 each, and thence from 9,000 as far as 3,000 by steps of 1,000. This last figure was made the limit, since it corresponds to a degree of expansion $n = 22.3$ which is very scarcely reached in practice. The column of calculated values for the degree of expansion n in the table of results shows that

$n = 5$, for a value of p_1 between 20,000 and 10,000,
$n = 10$, for a value of p_1 between 8,000 and 7,000,
$n = 15$, for a value of p_1 between 5,000 and 4,000,
$n = 20$, for a value of p_1 between 4,000 and 3,000.

For these four special values of n the problem has been solved by systematic interpolation (*tâtonnements méthodiques*) to find the values of $p_1, x_1, u_1, \ldots, n$ being given, and they have been inter-

calated in the table, as appears in Table I., appended. Finally, the diagram of results has been drawn on the same principle as that of the indicator.

Thereupon, all the same calculations were reproduced, but with an initial pressure of 60,000 kilograms to the square metre (Table II.), and the diagram has been traced on the same sheet and with the same axes as the preceding one. This plotting has brought out the fact that the adiabatic curve for 60,000 is almost superposed on the previous one for its entire length between $p_1 = 60{,}000$ and $p_1 = 2{,}000$. From this it must be concluded that, practically, for expansions less than 20, it could be supposed that the two curves coincide, and the consequences could then be deduced and the extent of error ascertained afterward. Having done this, confining attention only to the figures belonging to expansions whose degrees are 5, 10, 15, and 20, Table III. results :

TABLE III.

Cut-off n.	Value of AW_d.		Difference per cent.	Value of $\frac{p_0}{p_1}$.		Difference per cent.
	Exact.	Calculated (D').		Exact.	Calculated (D).	
			$p_0 = 100{,}000$.			
5	66.514	67.066	0.83	6.248	6.164	− 1.34
10	91.057	91.896	0.92	13.617	13.490	− 0.93
15	104.446	105.430	0.94	21.427	21.320	− 0.50
20	113.608	114.595	0.87	29.516	29.523	+ 0.02
			$p_0 = 60{,}000$.			
5	64.511	64.970	0.71	6.195	6.164	− 0.50
10	88.511	89.025	0.58	13.520	13.490	− 0.22
15	101.514	102.136	0.61	21.239	21.320	+ 0.38
20	110.444	111.014	0.52	29.226	29.523	+ 1.02

In the formula

$$pv^k = \text{constant},$$

the most convenient value for k has been sought, and this has been found to be 1.13, and the values (D) and (D'), deduced therefrom, have been introduced into Table III. in order to be compared with the exact values. It would appear that the

work of expansion, calculated from the proposed formula, is always too large, but by a quantity which remains always less than one per cent. of the exact result. The final pressure calculated from the formula (D) is sometimes too large and sometimes too small, but the calculated ratio between the extreme pressures differs from the exact ratio by a quantity less than one and a half per cent. of the exact result. Hence, practically, the formulas (D) and (D') are acceptable, and they have the advantage that they avoid the long calculations consequent upon the use of the formulas (d) and (d').

In spite of the fact that the action of the cylinder walls can materially modify the conclusions which can be drawn from the preceding theory, it is not needless to take account of the benefit from high pressures and great expansion, as it would be if engines could operate under the most favorable circumstances. To this end, Tables IV. and V. have been prepared, from whence these conclusions can be drawn: 1st, according to the degree of expansion, between the pressures 100,000 and 60,000, the difference in favor of the higher varies between 3.30 and 5.75 per cent. upon the efficiency, and between 4.5 and 7.3 per cent. on the consumption per horse-power per hour; 2d, the economy resulting from high expansion is nearly the same for the two values of the initial pressure, but is a little less for the lower pressure. Between the limits $n = 5$ and $n = 20$ the economy will be about 27 per cent. for $p_0 = 100{,}000$ and 25 per cent. for $p_0 = 60{,}000$. Even theoretically, between 15 and 20 the advantage is small; practically it is probably zero, if not negative.

TABLE I.

$p_0 = 100{,}000$

$\phi_0 + \frac{r_0}{T_0} = 1.57232$ $\qquad$ $\sigma_0 + x_0\mu_0 = 0.19626$

$Ap_0v_0 = 45.916$ $\qquad$ $\lambda_0 - q' = 625.954$

p_1	ϕ_1	$\phi_0 + \frac{r_0}{T_0} - \phi_1$	$\frac{r_1}{T_1}$	x_1	μ_1	σ_1	$\sigma_1 - x_1\mu_1$	$n = \frac{\sigma_1 + x_1\mu_1}{\sigma_0 + x_0\mu_0}$
100.000	0.51002	1.06230	1.0623	1.0000	0.19514	0.00112	0.19626	1.0000
90,000	0.49967	1.07265	1.0803	0.9929	0.21553	0.00111	0.21511	1.0960
80,000	0.48827	1.08405	1.1003	0.9852	0.24084	0.00111	0.23839	1.2147
70.000	0.47551	1.09681	1.1231	0.9766	0.27312	0.00110	0.26784	1.3647
60,000	0.46108	1.11124	1.1491	0.9671	0.31579	0.00109	0.30649	1.5617
50,000	0.44434	1.12798	1.1796	0.9562	0.37491	0.00109	0.35957	1.8321
40,000	0.42437	1.14795	1.2171	0.9432	0.46219	0.00108	0.43730	2.2282
30,000	0.39944	1.17288	1.2651	0.9271	0.60625	0.00107	0.56312	2.8693
20,000	0.36562	1.20670	1.3318	0.9060	0.88780	0.00106	0.80541	4.1038
16,005	0.34771	1.22461	1.3682	0.8951	1.0951	0.00105	0.98127	5.0000
10,000	0.31120	1.26112	1.4441	0.8733	1.7053	0.00105	1.49028	7.5954
9,000	0.30327	1.26905	1.4611	0.8686	1.8833	0.00104	1.63687	8.3403
8,000	0.29453	1.27779	1.4800	0.8634	2.1045	0.00104	1.81806	9.2635
7.344	0.28821	1.28411	1.4936	0.8597	2.2815	0.00103	1.96253	10.0000
7,000	0.28469	1.28763	1.5013	0.8577	2.3869	0.00103	2.04824	10.4364
6,000	0.27354	1.29878	1.5258	0.8512	2.7606	0.00102	2.35082	11.9781
5,000	0.26052	1.31180	1.5548	0.8437	3.2790	0.00101	2.76749	14.1011
4,667	0.25567	1.31665	1.5656	0.8410	3.4997	0.00100	2.94420	15.0000
4,000	0.24492	1.32740	1.5900	0.8348	4.0483	0.00100	3.38052	17.2247
3,388	0.23352	1.33880	1.6161	0.8284	4.7367	0.00100	3.92495	20.0000
3,000	0.22529	1.34703	1.6351	0.8238	5.3135	0.00100	4.37826	22.3034

TABLE I.—*Continued.*

$p_0 = 100{,}000$

$\phi_0 + \frac{r_0}{T_0} = 1.57232$ $\qquad$ $\sigma_0 + x_0\mu_0 = 0.19626$

$Ap_0v_0 = 45.916$ $\qquad$ $\lambda_0 - q' = 625.954$

p_1	q_1	r_1	x_1	$U_1 = q_1 + x_1\rho_1$	$AW_d = U_0 - U_1$	AW_c	AW	$\frac{AW}{\lambda_0 - q'}$	$\frac{270.000}{T'}$
100,000	181.243	433.901	1.0000	615.144	0.000	0.459	45.457	0.0726	13.976
90,000	176.563	437.477	0.9929	610.934	4.210	0.504	49.622	0.0793	12.803
80,000	171.493	441.358	0.9852	606.319	8.825	0.558	54.183	0.0866	11.725
70,000	165.886	445.657	0.9766	601.115	14.029	0.628	59.317	0.0948	10.710
60,000	159.624	450.467	0.9671	595.271	19.873	0.719	65.070	0.1040	9.763
50,000	152.475	455.969	0.9562	588.473	26.671	0.843	71.744	0.1146	8.855
40,000	144.089	462.439	0.9432	580.261	34.883	1.026	79.773	0.1274	7.964
30,000	133.852	470.357	0.9271	569.920	45.224	1.322	89.818	0.1435	7.073
20,000	120.359	480.828	0.9060	555.989	59.155	1.893	103.178	0.1648	6.157
16,005	113.389	486.249	0.8951	548.630	66.514	2.306	110.124	0.1759	5.769
10,000	99.566	497.029	0.8733	533.621	81.523	3.504	123.935	0.1980	5.126
9,000	96.628	499.325	0.8686	534.342	84.802	3.849	126.869	0.2027	5.007
8,000	93.416	501.835	0.8634	526.700	88.444	4.275	130.085	0.2078	4.884
7.344	91.108	503.640	0.8597	524.087	91.057	4.615	132.358	0.2114	4.800
7,000	89.832	504.639	0.8577	522.661	92.483	4.817	133.582	0.2134	4.756
6,000	85.815	507.784	0.8512	518.041	97.103	5.529	137.490	0.2196	4.621
5,000	81.182	511.414	0.8437	512.662	102.482	6.509	141.889	0.2267	4.477
4,667	79.469	512.757	0.8410	510.698	104.446	6.925	143.437	0.2291	4.429
4,000	75.704	515.710	0.8348	506.219	109.925	7.952	147.889	0.2363	4.296
3,388	71.754	518.810	0.8284	501.536	113.608	9.233	150.291	0.2400	4.227
3,000	68.930	521.028	0.8238	498.153	116.991	10.297	152.610	0.2438	4.168

TABLE II.

$p_0 = 60{,}000.$

$\phi_0 + \frac{r_0}{T_0} = 1.61018$ $\qquad$ $\sigma_0 + x_0\mu_0 = 0.31688$

$Ap_0\mu_0 = 44.582$ $\qquad$ $\lambda_0 - q' = 619.567.$

p_1	ϕ_1	$\phi_0 + \frac{r_0}{T_0} - \phi_1$	$\frac{r_1}{T_1}$	x_1	μ_1	σ_1	$\sigma_1 + x_1\mu_1$	$\mu = \frac{\sigma_1 + x_1\mu_1}{\sigma_0 + x_0\mu_0}$
60,000	0.46108	1.14910	1.1491	1.0000	0.31579	0.00109	0.31688	1.0000
50,000	0.44434	1.16584	1.1796	0.9883	0.37491	0.00109	0.37161	1.1727
40,000	0.42437	1.18581	1.2171	0.9743	0.46249	0.00108	0.45168	1.4254
30,000	0.39944	1.21074	1.2651	0.9570	0.60625	0.00107	0.58125	1.8343
20,000	0.36562	1.24456	1.3318	0.9345	0.88780	0.00106	0.83071	2.6215
10,000	0.31120	1.29898	1.4441	0.8995	1.7053	0.00105	1.53497	4.8440
9,686	0.30878	1.30140	1.4494	0.8979	1.7573	0.00104	1.57886	5.0000
9,000	0.30327	1.30691	1.4611	0.8945	1.8833	0.00104	1.68565	5.3195
8,000	0.29453	1.31565	1.4800	0.8890	2.1045	0.00104	1.87194	5.9074
7,000	0.28469	1.32549	1.5013	0.8829	2.3869	0.00103	2.10842	6.6537
6,000	0.27354	1.33664	1.5258	0.8760	2.7606	0.00102	2.41931	7.6348
5,000	0.26052	1.34966	1.5548	0.8680	3.2790	0.00101	2.84718	8.9850
4,438	0.25215	1.35803	1.5736	0.8630	3.6702	0.00100	3.16833	10.0000
4,000	0.24492	1.36526	1.5900	0.8587	4.0483	0.00100	3.47728	10.9735
3,000	0.22529	1.38489	1.6351	0.8470	5.3135	0.00100	4.50153	14.2058
2,825	0.22124	1.38894	1.6444	0.8447	5.6257	0.00100	4.75284	15.0000
2 053	0.20014	1.41004	1.6941	0.8323	7.6125	0.00100	6.33699	20.0000
2,000	0.19845	1.41173	1.6981	0.8314	7.7992	0.00100	6.48525	20.4660

TABLE II.—*Continued.*

$p_0 = 60{,}000.$

$\phi_0 + \frac{r_0}{T_0} = 1.61018$ $\qquad$ $\sigma_0 + x_0\mu_0 = 0.31688$

$Ap_0\mu_0 = 44.582$ $\qquad$ $\lambda_0 - q' = 619.567.$

p_1	q_1	ρ_1	x_1	$U_1 = \eta_1 + x_1\rho_1$	$AW_1 = U_0 - U_1$	AW_2	AW	$\frac{AW}{\lambda_0 - q'}$	$\frac{270.000}{T}$
60.000	159.624	450.467	1.0000	610.091	0.000	0.743	43.839	0.0708	14.492
50.000	152.475	455.969	0.9883	603.109	6.982	0.872	50.692	0.0818	12.532
40.000	144.089	462.439	0.9743	594.643	15.448	1.060	59.970	0.0968	10.594
30.000	133.852	470.357	0.9570	583.984	26.107	1.365	69.324	0.1119	9.164
20.000	120.359	480.828	0.9345	569.693	40.398	1.952	83.028	0.1340	7.652
10.000	99.566	497.029	0.8995	546.644	63.447	3.609	104.420	0.1685	6.084
9.686	98.666	497.732	0.8979	545.580	64.511	3.713	105.380	0.1701	6.028
9.000	96.628	499.325	0.8945	543.274	66.817	3.964	107.435	0.1734	5.913
8.000	93.416	501.835	0.8890	539.547	70.544	4.402	110.724	0.1787	5.738
7.000	89.832	504.639	0.8829	535.368	74.713	4.959	114.336	0.1845	5.556
6.000	85.815	507.784	0.8760	530.634	79.457	5.690	118.349	0.1910	5.368
5.000	81.182	511.414	0.8680	525.089	85.002	6.697	122.887	0.1983	5.170
4.438	78.236	513.724	0.8630	521.580	88.511	7.453	125.640	0.2028	5.056
4.000	75.704	515.710	0.8587	518.544	91.547	8.180	127.949	0.2065	4.965
3.000	68.930	521.028	0.8470	510.241	99.850	10.589	133.843	0.2160	4.747
2,825	67.550	521.111	0.8447	508.577	101.514	11.181	134.915	0.2178	4.709
2.053	60.446	527.696	0.8323	499.647	110.444	14.908	140.118	0.2262	4.534
2.000	59.885	528.137	0.8314	498.978	111.113	15.259	140.436	0.2267	4.524

TABLE IV.

Cut-off n.		$p_0 = 100{,}000$.	$p_0 = 60{,}000$.	Difference per cent.
5	Ratio between p_0 and p_1	6.248	6.195	+0.09
	Final quality x_1	0.8951	0.8979	−0.03
	Efficiency	0.1759	0.1701	+3.30
	Water per horse-power per hour	5.769	6.028	−4.50
10	Ratio between p_0 and p_1	13.617	13.520	+0.07
	Final quality x_1	0.8597	0.8630	−0.04
	Efficiency	0.2114	0.2028	+4.07
	Water per horse-power per hour	4.800	5.056	−5.33
15	Ratio between p_0 and p_1	21.427	21.339	+0.09
	Final quality x_1	0.8410	0.8447	−0.04
	Efficiency	0.2291	0.2178	+4.93
	Water per horse-power per hour	4.429	4.709	−6.32
20	Ratio between p_0 and p_1	29.516	29.226	+0.10
	Final quality x_1	0.8284	0.8323	−0.05
	Efficiency	0.2400	0.2262	+5.75
	Water per horse-power per hour	4.227	4.534	−7.26

TABLE V.

Cut-off n.	$p_0 = 100{,}000$.				$p_0 = 60{,}000$.			
	Water per H.P. per hour.	Per cent. of economy for different degrees of expansion.			Water per H.P. per hour.	Per cent. of economy for different degrees of expansion.		
		5	10	15		5	10	15
5	5.769	.....	.....	.....	6.028	.....	.....	.....
10	4.800	16.80	.....	.....	5.056	16.22	.....	.....
15	4.429	23.23	7.73	.....	4.709	21.88	14.77	.....
20	4.227	26.73	11.94	4.56	4.534	24.78	10.32	3.72

DXXVIII.*

ROD-ROLLING MILLS AND THEIR DEVELOPMENT IN AMERICA.

BY FRED. H. DANIELS, WORCESTER, MASS.

(Member of the Society.)

THE subject of rod rolling in America, prior to 1876, attracted little attention except among the various wire manufacturers; although the introduction of Bessemer and Open Hearth steel for wire purposes, as early as March, 1871, at the Grove Street Works of the Washburn & Moen Manufacturing Co., was the initiation of a development of the rod-rolling industry in this country.

The substitution of Bessemer and Open Hearth steel for puddled and charcoal iron gave to the rod rollers and wire manufacturers the ideal material from which to produce wire rods and wire, furnishing a product which was far less expensive and also more satisfactory.

It is a remarkable fact that this beginning of modern American wire-rod rolling occurred only two years previous to the first manufacture of barbed wire, which was in the fall of 1873, at De Kalb, Illinois. Mr. J. F. Glidden then produced a few hundred feet, but the process was very crude when compared with the present effective and rapid methods.

Previous to 1873 wire fencing was made in considerable quantities for the West, largely from puddled and piled scrap iron, Nos. 8 and 9 drawn wire, but this material did not give complete satisfaction. The perfecting of machinery for cheaply producing barbed fence wire during the years from 1873 to 1876, by the Washburn & Moen Manufacturing Co., and, shortly after, the introduction of wire nails into this country, coupled with the installation of Bessemer and Open Hearth steel plants in the United States, combined to revolutionize the wire-rod rolling mill.

The part which barbed wire and nails have played in this

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revolution can be best illustrated by a statement of growth. In 1874, from an output of about five tons of barbed wire, the production has reached a total yearly for the United States of about 200,000 gross tons; and the production of wire nails, the use of which was scarcely known in this country ten years ago, except to importers of crated and boxed goods, who had to wrestle with the toughness and holding qualities of the German and French wire nails, has now reached a sum total yearly of 200,000 gross tons and is rapidly driving the cut nail out of the market.

The increased demand for wire rods rendered larger productions imperative and stimulated competition among the various mills. Hence very rapid developments have taken place up to the present time.

Wire drawing was one of the early industries introduced into America, as early as 1666 (according to Bishop). The wire was used largely for the manufacture of pins and wool cards. Wire rods were unknown at that time, as the use of grooved rolls, so far as we are informed, had not been suggested or had not been reduced to practice.

The wire drawer in those days depended upon the rolling and slitting mill for his rolled product. Charcoal iron, made directly from the ore and rolled into plates, which were sheared into strips or square rods, formed the supply for the pioneer wire drawer.

This was, without doubt, the universal practice in Europe until the year 1783, when Cort patented and introduced the use of grooved rollers, thereby originating what has since become one of the most successful and important inventions for reducing metals into all kinds of forms and shapes.

Very little was accomplished in this country, however, in rolling and slitting, until after the Revolutionary War, when rolling mills were rapidly built throughout New England and the Middle States, the product being employed chiefly in making nail rods, pins, and card wire.

This system of producing wire rods remained in vogue, without material advancement, until between 1830 and 1840. One of the first improvements, if not the first, was made at Fall River, where a rod mill was built by the Fall River Iron Works Co. The original mill was erected in 1839, and an addition made to it in 1841. This mill was driven by bevel gears. It was

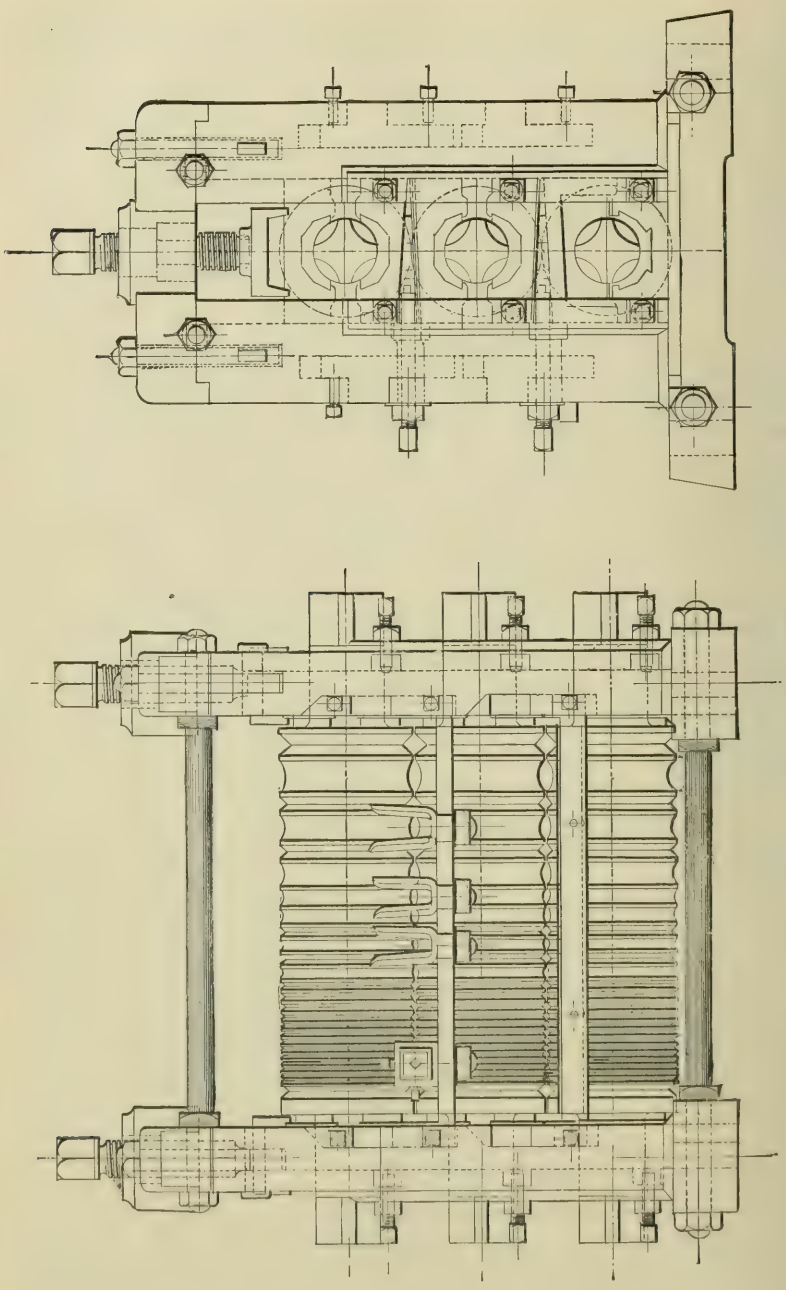
destroyed by fire and rebuilt in 1843. The power for the new mill was communicated from the engine by belts. This mill had a system of pulleys of different sizes, so that the speed could be changed when required. The train consisted of three sets of rolls, and the reel was turned with a hand crank. The output of the original mill was about three tons per turn, of rods not smaller than one quarter of an inch, the coils weighing about ten pounds. The billets were one and one-fourth inches square, and made either from piled scrap, puddled, or charcoal iron.

After the mill was rebuilt in 1843, with better driving facilities, increased speed and diameters of rolls, and the introduction of belts to drive the mill, the weight of the billet was increased to about 25 lbs., and rods were rolled as small as three-sixteenths of an inch in diameter. The mill was never changed after being rebuilt, and the production was from five to eight tons a day, depending upon the size of rods. (I am indebted to Messrs. Philip D. Borden and Robert C. Brown, of Fall River, for the above information.)

Mills after the Fall River design were erected in various parts of the United States by the Roeblings, Prov. Iron Co., Henry S. Washburn & Co., Cooper & Hewitt, Windsor Locks Co., and at Troy and other places. Probably the best illustration of the form of mill that was in general use in America from 1830 to 1860 is found in that built by Ichabod and Charles Washburn at Quinsigamond, now the Quinsigamond Works of the Washburn and Moen Manufacturing Co. (See Figs. 207, 208, and 209.) This mill was driven either by a water wheel or by steam, as desired.

There was much rivalry in those days between the various rod mills, and when the Quinsigamond mill produced a little over nine long tons of No. 4 wire rods, 20 to 30 lbs. per bundle, in one turn, it was considered a very remarkable output, and was the banner record for many years. I am informed by Mr. William Garrett, member of the Society, that he has lately produced at Joliet, in one turn of ten hours, as high as 314.000 lbs. or 140 long tons of No. 5 rods, 150 lbs. per bundle. All of this increase in twenty years.

Until 1860 looping mills were unknown, the billet being passed through the rolls back and forth, and this no doubt accounts for the light weight of billet used up to that time. The reel was also turned by hand.



ROUGHING ROLL STAND. QUINSIGAMOND OLD ROD MILL

Fig. 207.

The demand for telegraph, suspension bridge, and rope wires in long lengths caused the manufacturers of wire rods to give careful attention to the question of improved rod-rolling facilities.

Mr. Ichabod Washburn, during a visit to England, made the acquaintance of Mr. George Bedson, Superintendent of the Richard Johnson & Nephew Wire Works, Manchester. Messrs. Washburn and Bedson afterwards became warm friends, and an extensive correspondence and exchange of ideas regarding wire-making passed between them. Bedson was, without doubt, the best informed and most skilled wire and rod expert in Europe. Mr. Washburn was informed by Mr. Bedson, from time to time, during the sixties, regarding his experiments in the direction of rolling wire rods continuously, at the Richard Johnson & Nephew Wire Works, and he became very enthusiastic regarding the possibilities in this direction.

In addition to the advantages to be derived from wire rods in long lengths, Messrs. Bedson and Washburn at an early date perceived the possibilities of rolling wire rods of small cross section, as small, if not smaller, than No. 8 wire gauge. Mr. Washburn decided that a Bedson mill would be of great advantage to his company, and he personally assumed the responsibility and expense and contracted for a mill.

In the fall of 1869, one of Bedson's continuous wire-rod rolling mills was erected at the Grove Street Works of the Washburn & Moen Manufacturing Co. (Fig. 210.) Applications for patents on this system were filed in the U. S. Patent Office, but the main invention was anticipated by a similar invention made in the United States by Henry B. Comer.

In Patent No. 23,425, dated March 29, 1859, Mr. Comer described his improvement as follows:

"The nature of this invention consists in a mechanical arrangement for rolling iron, by causing the iron to be rolled to pass between a series of rolls and through guides, the grooves in the rolls and the form of the guides being adapted in form and size to the article desired."

"Claim—Finishing rolls which are placed in front of each other and on parallel lines, with guides placed between each set of rolls, said guides being so constructed that they will guide and change the position of the iron as it passes from one set of rolls to another set, as described and set forth."

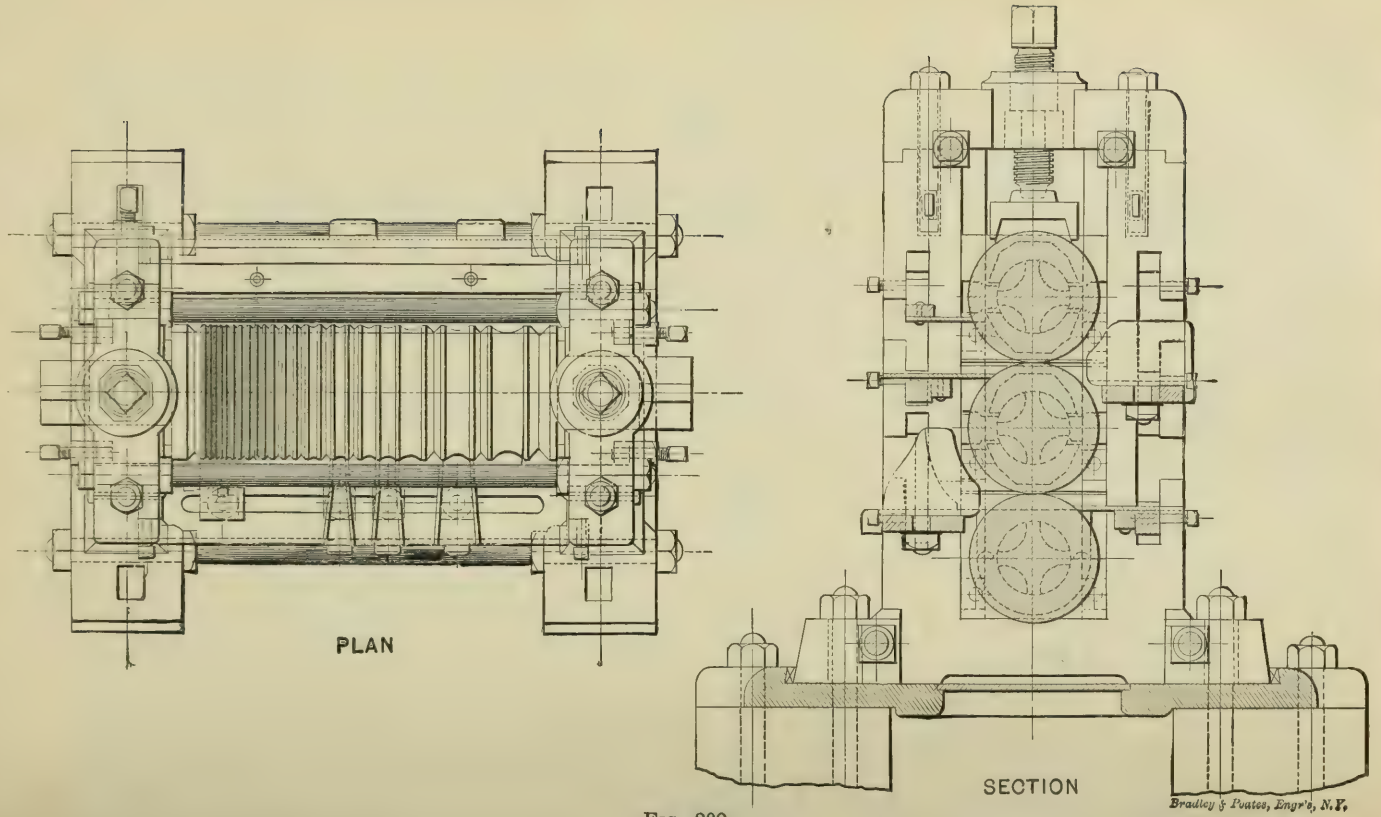


FIG. 208.

Roughing Roll Stand, Quinsigamond Old Rod Mill.

Mr. Washburn immediately obtained the Comer interest by purchase. It has always been considered by the Washburn & Moen Manufacturing Co. that Comer was the first to propose, in the United States, the continuous rolling system, and that Bedson was the first in England; Bedson, however, having the credit of reducing the invention to practice and successfully installing, both in England and America, the system for continuously producing wire rods.

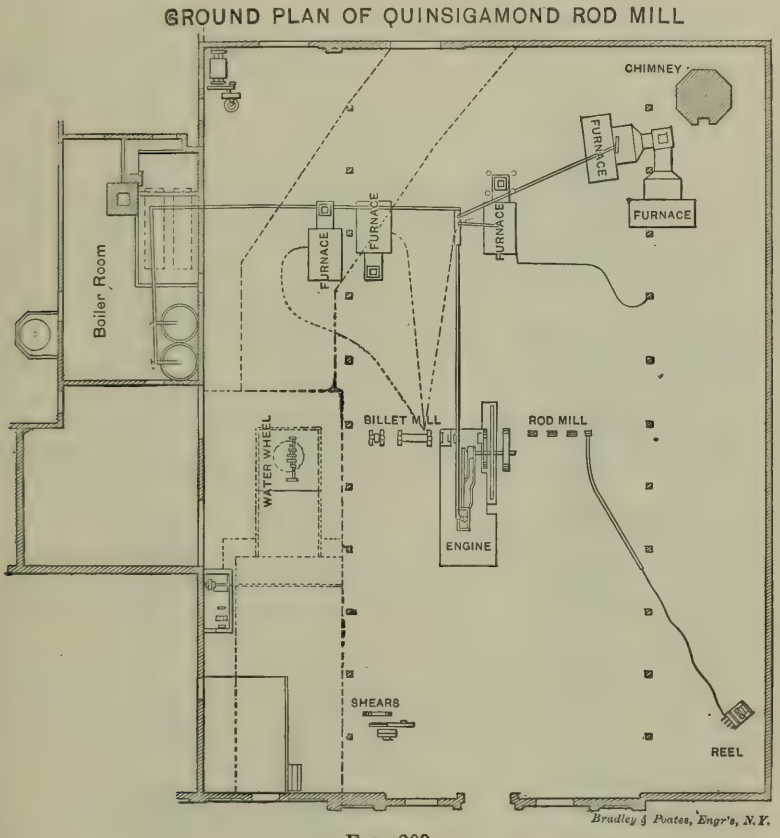


Fig. 209.

All attempts made by Comer in the direction of continuous rolling were failures. George Bedson, after repeated experiments and persistent endeavors, overcoming almost insurmountable obstacles, succeeded in installing a mill at Manchester which was a success, producing telegraph wire rod in bundles of 100

lbs. and over, and as small as No. 8 wire gauge. (This mill, as originally built, is fully illustrated in Fig. 210.)

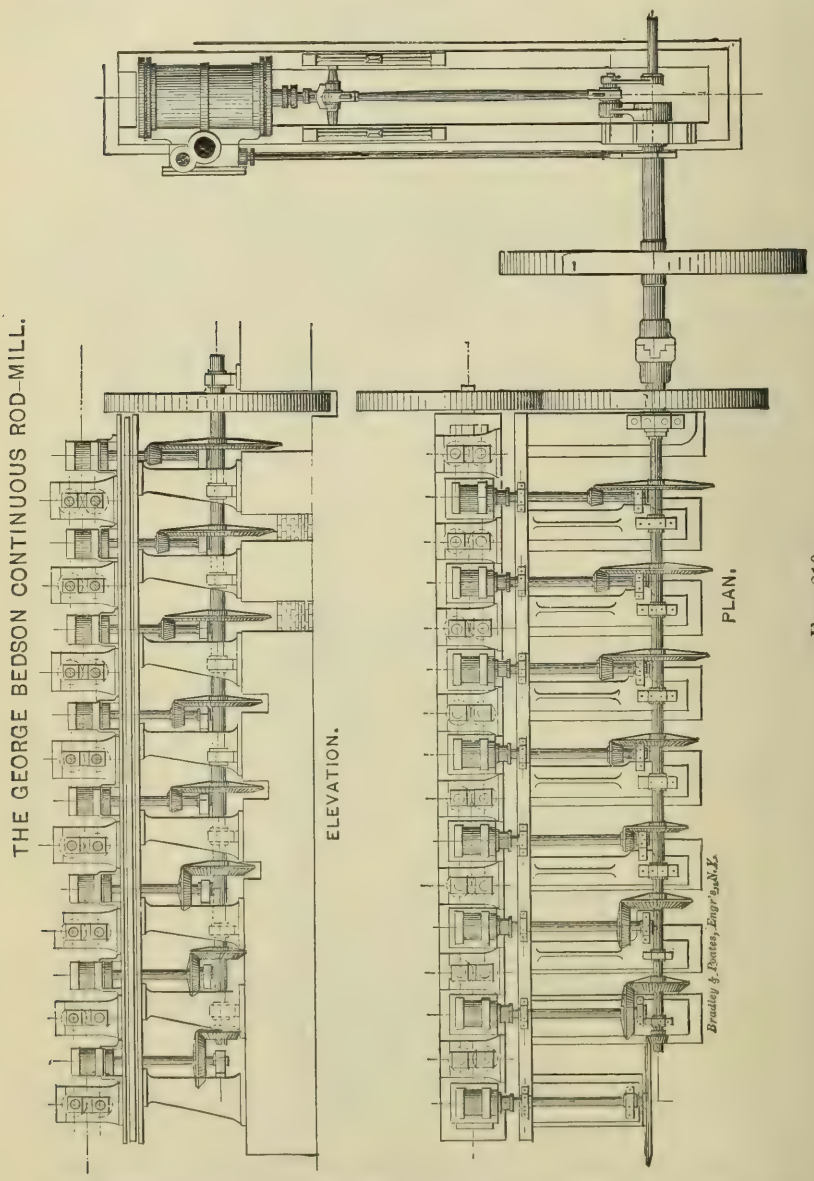


FIG. 210.

The billets, one to two inches square, were heated in a Siemens gas furnace, which was from 18 to 30 feet long. The first pair

of rolls in the continuous train were located about two feet from the delivery door of the heating furnace, the billets being charged into the furnace from the opposite end. The billet, after passing continuously through the several pairs of rolls, was delivered in an oval shape from the last pair of continuous rolls, and was seized with tongs by a workman, who looped the rod and introduced the first end into a finishing pair of rolls which finished the wire rod. This finishing pair is not shown in the plate.

Mr. Bedson desired that the entire system, from the billet to the wire rod, should be continuous, and added a finishing pair of rolls in the line of the continuous train. A trial was made, which was successful, and the rollers were instructed to continue by this system. Returning in the afternoon, Mr. Bedson's English ire was aroused by discovering the finishing rolls removed and the mill running according to the old system. The writer was well acquainted with Mr. Bedson (now deceased), and well remembers the pleasure Mr. Bedson had in relating how he overcame the opposition of the workmen to this innovation. He ordered the mill stopped, sent for mechanics, had the old finishing housing taken to the drop and broken into scrap, and the new finishing housing put in place. The rollers were then informed that there was the mill, and they could roll or not as they saw fit.

Mr. Bedson encountered difficulty in obtaining the exact increase in speeds for the several pairs of rolls in his mill, but, after much experimenting, he reached a successful plan by which the surface speed of every pair of rolls was accurately determined. A billet of the required size was taken and the length measured exactly. This was heated and passed through the rolls of an ordinary rod-rolling mill the required number of times to reduce the billet to the size of wire rod desired, each groove being carefully proportioned for the proper reduction in area, and after each pass the piece was measured accurately. Thus the surface speeds of rolls were easily obtained by measuring the elongation after each pass.

As stated before, it has been generally understood by the Washburn & Moen Manufacturing Co. and others that Comer was the first to suggest, and Bedson the first to reduce to practice in America, the continuous rolling-mill system, having twisting guides to conduct the metal from one pair of rolls to the next;

and large royalties were paid to Bedson and to Comer for the use of this system.

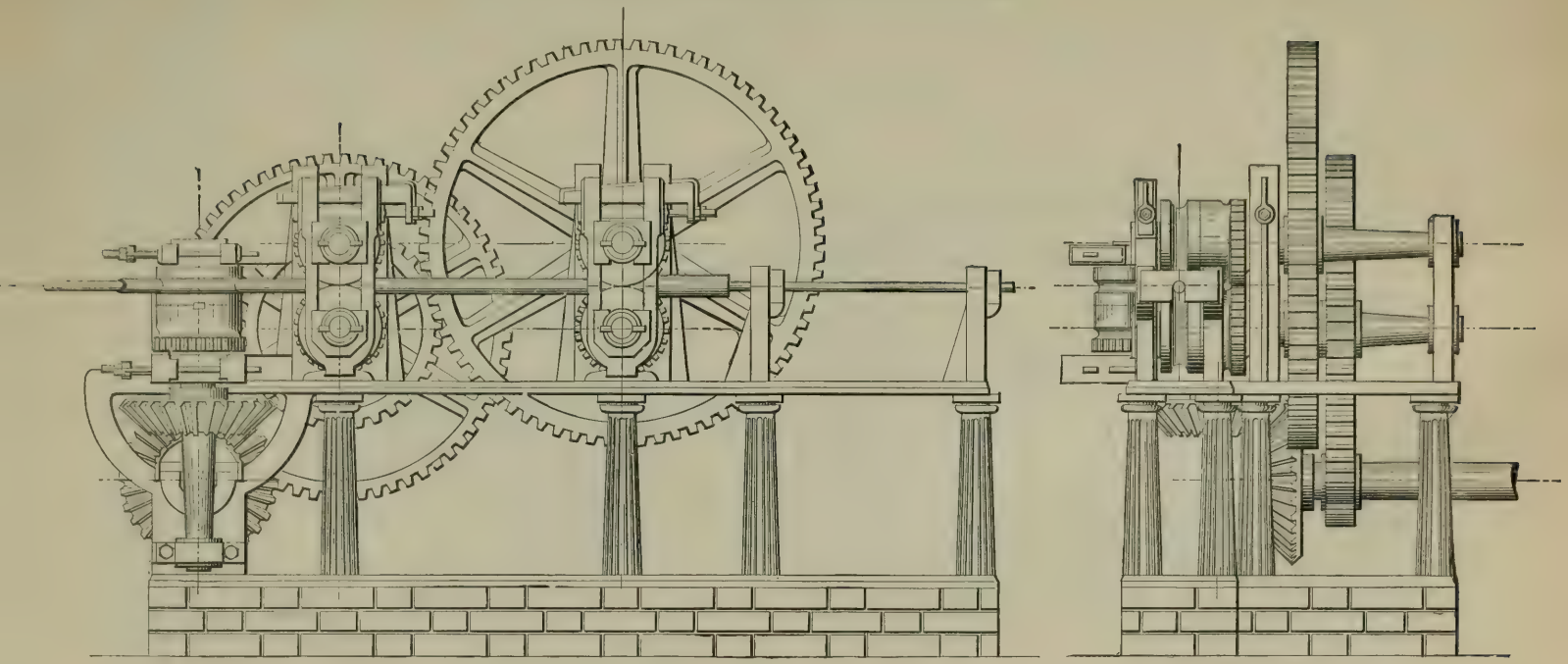
A short time ago the writer accidentally came across a patent, in the U. S. Patent Office, which upsets these conclusions and shows that the credit for the suggestion of continuous rolling and the reduction to practice belongs in the United States. This patent had been lost sight of for many years, the original manuscript having been tucked away in one of the many pigeonholes in the Patent Office. It was lately discovered by one of the examiners, and copies of the patent were printed. (This patent is to J. E. Serrell, for making metallic tubing, No. 2918, patented January 20, 1843.)

Mr. Serrell certainly knew how to draw up a complete and comprehensive claim, and on account of its importance it is inserted here.

"Claim 1—The arrangements and application of mechanical means, as herein described, for reducing pieces or ingots of metal, or mixtures of metals, or combinations of metal, into pipes or tubes, or into bars, rods, wire, or other forms, by the operation of any number of pairs of grooves, beaded, indented, raised, or hollowed rollers, either set in lines parallel to each other or at an angle to each other, or both angular and parallel rollers combined, when such pairs of rollers or combinations of pairs of rollers travel, work, or move at speeds successively increasing according to the amount of extension in length caused by the reduction of the area effected by each preceding pair of rollers, so that the finally required form of metal shall be reduced by the action of the last pair of rollers on the metal or metals of any ingot operated on in the manner herein substantially described and set forth."

We are informed by Lemuel W. Serrell, Esq., of New York, the well-known patent attorney, brother of the late J. E. Serrell, that the invention was perfected and put in use to a considerable extent in 1842 to 1845. The machine was used in the manufacture of lead pipe, and considerable of the Morse telegraph wire first laid between Washington and Baltimore was prepared on this machine. That is to say, the speeded rolls were made use of, and they drew the pipe down from an ingot that was cast progressively in a mould by a column of melted lead, and the covered wire went through a stationary hollow mandrel, upon which the lead pipe was reduced quite thin, and the last two

THE J. E. SERRELL CONTINUOUS MILL.



FRONT ELEVATION.

END ELEVATION.

Fig. 211.

pairs of rolls pressed the lead pipe closely upon the insulated wire. This machine was also used in the manufacture of lead pipe for Croton water, and considerable of it had a lining of tin

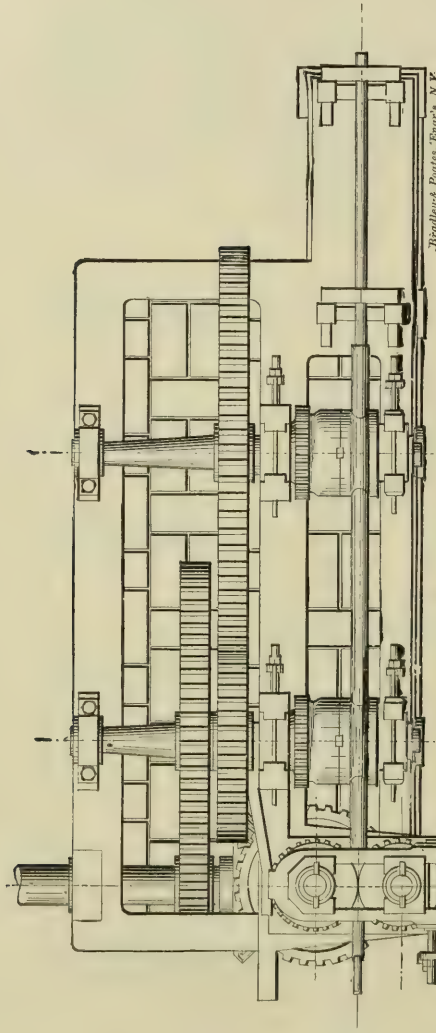


FIG. 212.

The J. E. Serrell Continuous Mill.

that was cast as a tube within the lead ingot, and the two were drawn down together. Experiments were made with the machine in connection with the manufacture of wire rods for horse-shoe nails, but it was never used practically for that purpose.

The Serrell Mill was operated on the corner of Canal and Elm Streets, in New York city. (The Serrell Continuous Mill is fully illustrated in Figs. 211 and 212.)

Mr. Serrell, without doubt, was the first to employ rolls each speeded higher than the preceding, whereby continuous rolling was rendered possible, and it is evident that it was his intention to claim this, as broadly as language could express.

The Bedson Wire-Rod Rolling Mill, including the engines, erected at the Washburn & Moen Works in 1869, was built in England, and expert English rollers were employed to run it. The billets first used in this mill were 1¼ inches square, but were gradually increased in length, from time to time, being at first 20 feet and later 28 feet, and were obtained from Europe, mostly from Sweden. The wire made from these billets was used principally for telegraphic purposes.

Mr. Washburn and others had great hopes for the future of this mill, believing that the problem of obtaining bundles of wire rods weighing 100 lbs. and over was solved. The billets were heated in a Siemens gas furnace, one of the first erected in America, and the arrangement and design of both furnace and mill were similar to the first furnace and mill built by Bedson in England.

The reeling facilities were the same that had been before used, the reel being turned by hand; but, shortly after the Bedson Mill started (or, more justly, the Serrell-Comer-Bedson Mill), a power reel, operated by a loose running belt, a binder, and a frictional device for stopping the reel, was put in use. This suggestion, although simple, has been an important element in the development of rod rolling, increasing the efficiency and output, and reducing the cost of rolling. (Fig. 213 illustrates the first power reel.)

The power reel was soon introduced into the Cambria Iron Company's rod mill, and afterwards adopted by Mr. Garrett, as well as by all the rod-rolling mills in the United States, and by Mr. Bedson in England. Mr. Garrett utilized two such reels for reeling two rods from one pair of finishing rolls.

Few realize the difficulties which were encountered in operating a continuous rod mill, especially during the period prior to the introduction of Bessemer and Open Hearth steel. It was impossible to obtain iron of uniform quality, sound and homogeneous, and it was up-hill work to obtain satisfactory results.

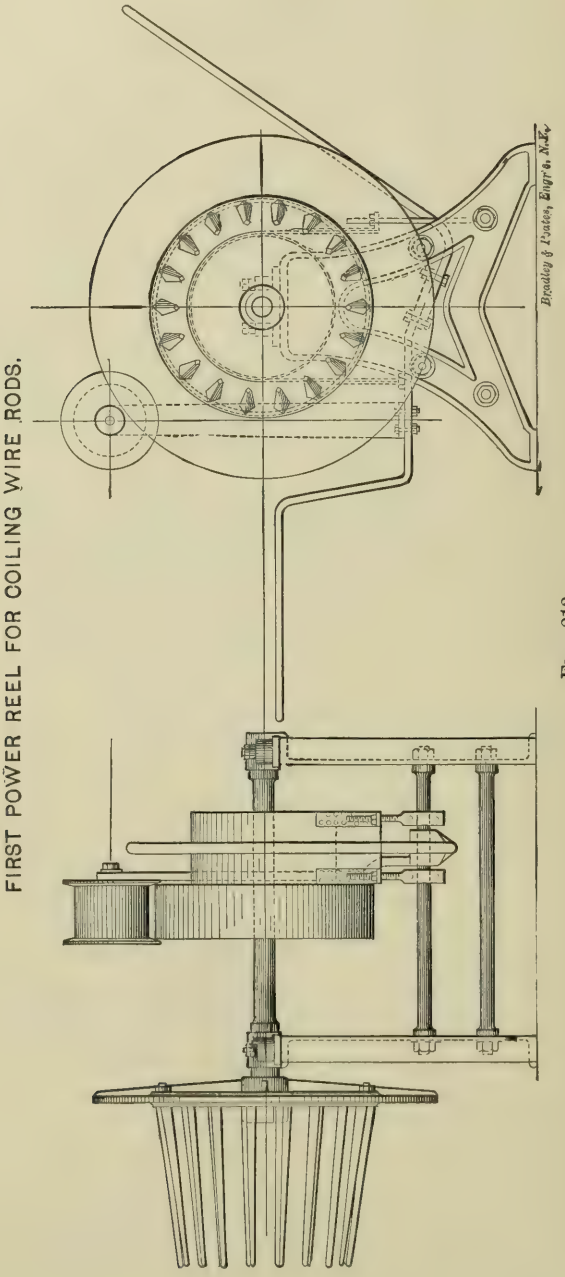

FIRST POWER REEL FOR COILING WIRE RODS.
Broadley & Yeaton, Engr's, N.Y.

Fig. 213.

The output was small, not exceeding from eight to ten tons a turn, and the cobbles and breakdowns were frequent and serious.

After persistent and continued endeavor, and by strengthening the gearing, shafts, and, in fact, rebuilding the entire mill, the production was somewhat increased, yet the quality of rods from the mill was not satisfactory for telegraphic purposes. The only element which gave complete satisfaction was the increased weight of the bundle.

It gradually became apparent to those who had to do with this mill, that the continuous system was not suitable for rolling iron wire. This conclusion was reached about the time that soft steel was suggested for wire purposes. As before stated, in March, 1871, after rolling a few trial lots of steel billets on the Bedson Mill, it was evident that this material possessed the necessary homogeneity and tensile strength (which iron lacked), when in a heated condition, to be rolled continuously with success.

Shortly after the introduction of steel, and about 1876, improvements were made in the engines for driving the mill, and the speed of the mill increased. These two changes increased the production to about 20 tons per turn. Later, in 1887, automatic reels were put in, doubling the production; that is, making it from 40 to 45 tons per turn.

Better facilities for rolling wire rod have now taken the place of the Bedson Mill, and in 1890 the entire plant was put into the scrap. (Figs. 214, 215, and 216 will illustrate the mill just before being dismantled.)

But other wire makers, during 1870 to 1880, were at the front in the line of improved rod-rolling facilities, among them being Messrs. Cooper & Hewitt and John A. Roebling & Sons.

The old system of passing the rod back and forth was rapidly discarded after 1870, and the Belgian system of seizing the first end of the rod as it issued from the rolls was attempted, but only one or two loops in the rolling operation were undertaken at first, the other passes being back and forth. The adoption of this system increased the output and also made it practicable to roll a heavier billet; and it was common practice in old mills to roll a double length billet, in the old length of furnace, by bending the billet in the middle so that the two ends came together, and straightening it out as it entered the first pair.

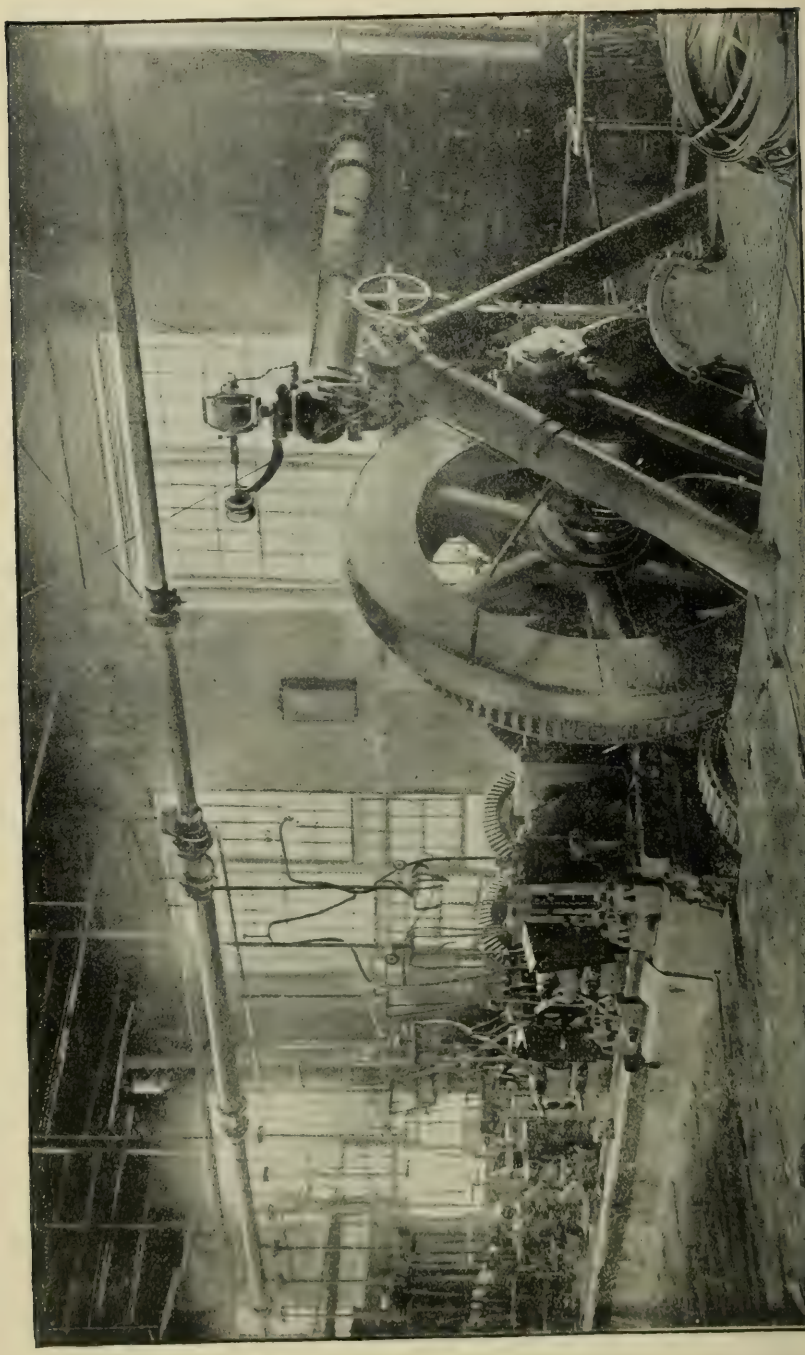


FIG. 214.

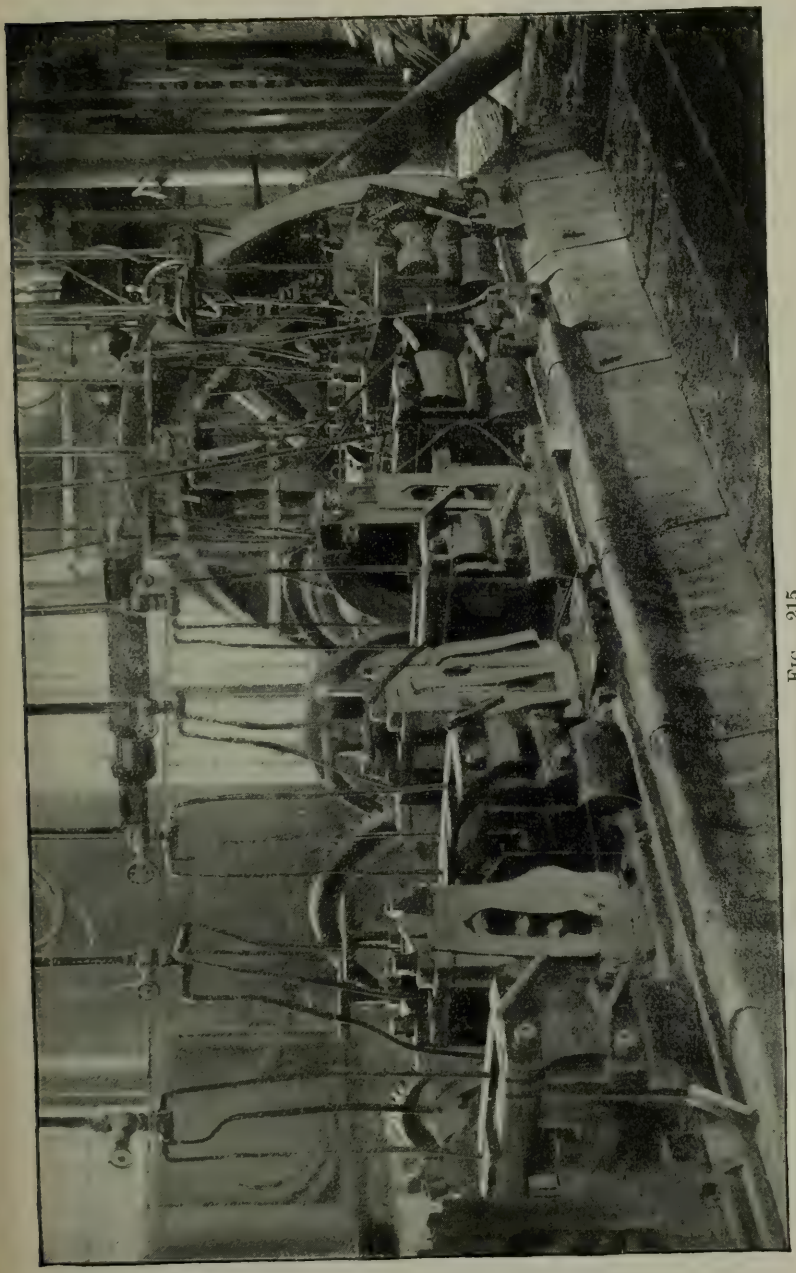


FIG. 215.

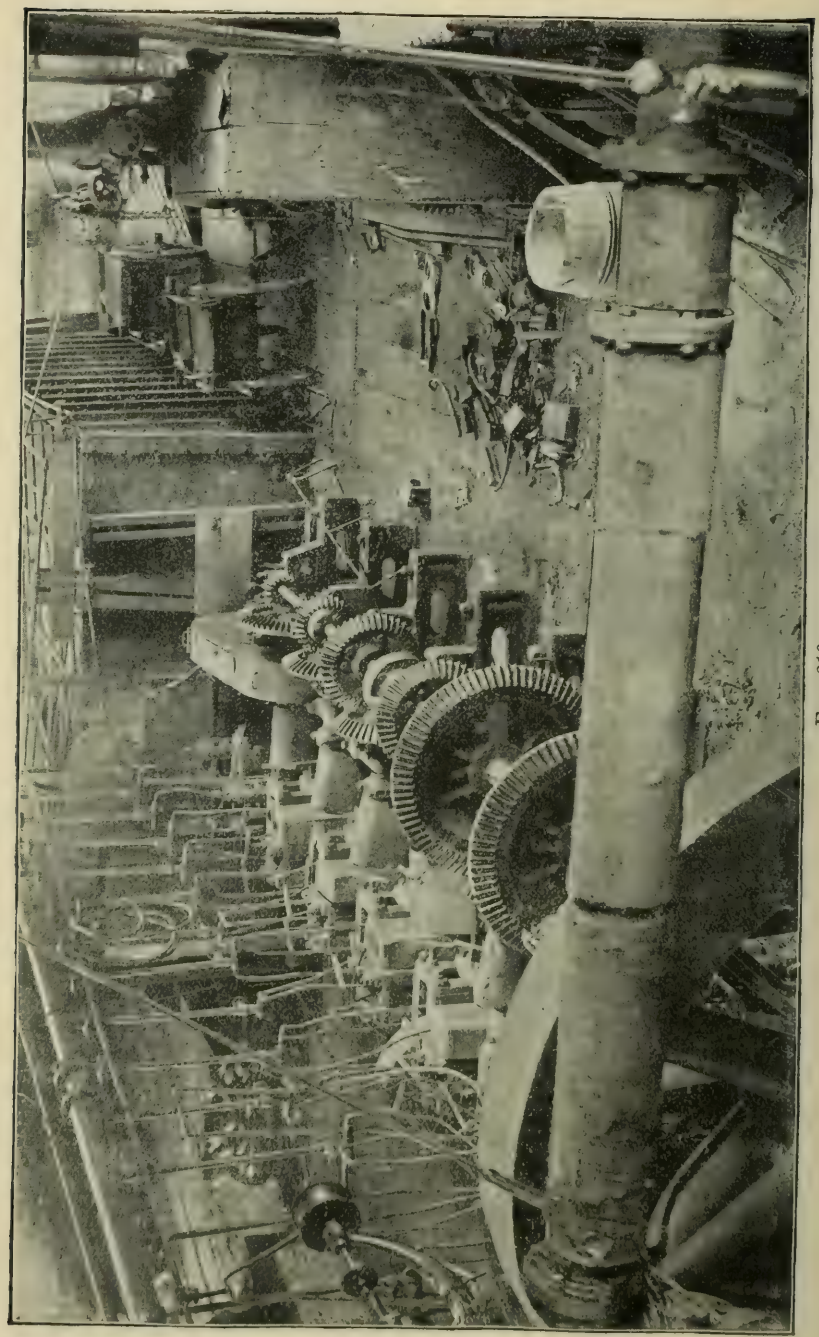


FIG. 216.

But with the introduction of steel-wire billets, new rod mills were erected throughout the United States, which entirely dispensed with the old back-and-forth system of rolling, a loop being formed between each pair of rolls. The introduction of this system and the power reel again increased the weight of billets to about 100 lbs., and the size of wire rods was reduced to No. 5, and in some cases to No. 6.

As the Bedson continuous system never gave satisfaction when producing iron-wire rods, the Washburn & Moen Manufacturing Co. erected in 1876 a Belgian rod mill, on the back-and-forth and looping plan combined, and with a sloping floor for the loops. This mill was arranged to take billets from four inches square or smaller, and these billets were passed back and forth through three high roughing rolls, until a size about $1\frac{1}{8}$ inches was reached, when they were passed through the Belgian train, where they were rolled to as small as No. 6. The output was as high as twenty to forty tons in ten hours, depending on size.

There was a peculiarity in the system of heating, the first furnace being a pre-heating furnace, the second heating the metal to the proper temperature for rolling, after transferring from the first to the second. We understand this mill to have been the first in America where four loops were formed at the same time, between two pairs of rolls. Of course it will be understood that only one rod was finished at a time in this mill, as, in this case, each of the loops were formed from the same rod and represented the different reductions. Fig. 217 illustrates the mill known at Washburn & Moen's as the Belgian Rod Mill, originating probably in Belgium or Germany, and the mill which has been in general use in Europe for years.

We now come to that period in the history of rod-rolling in the United States where the development has been so rapid and the production so increased as to astonish even the most sanguine of our rod rollers, and I am sure it will surprise our friends from abroad when they learn what is now accomplished.

There are practically only two systems in use in America at the present time; first, the combined back-and-forth and looping system, requiring expert roughers and catchers for all the oval passes and repeaters for square passes; and, second, the continuous system, which is almost wholly automatic throughout in its operation, that is, dispenses largely with hand labor.

By the first system are produced two-thirds of all the rods

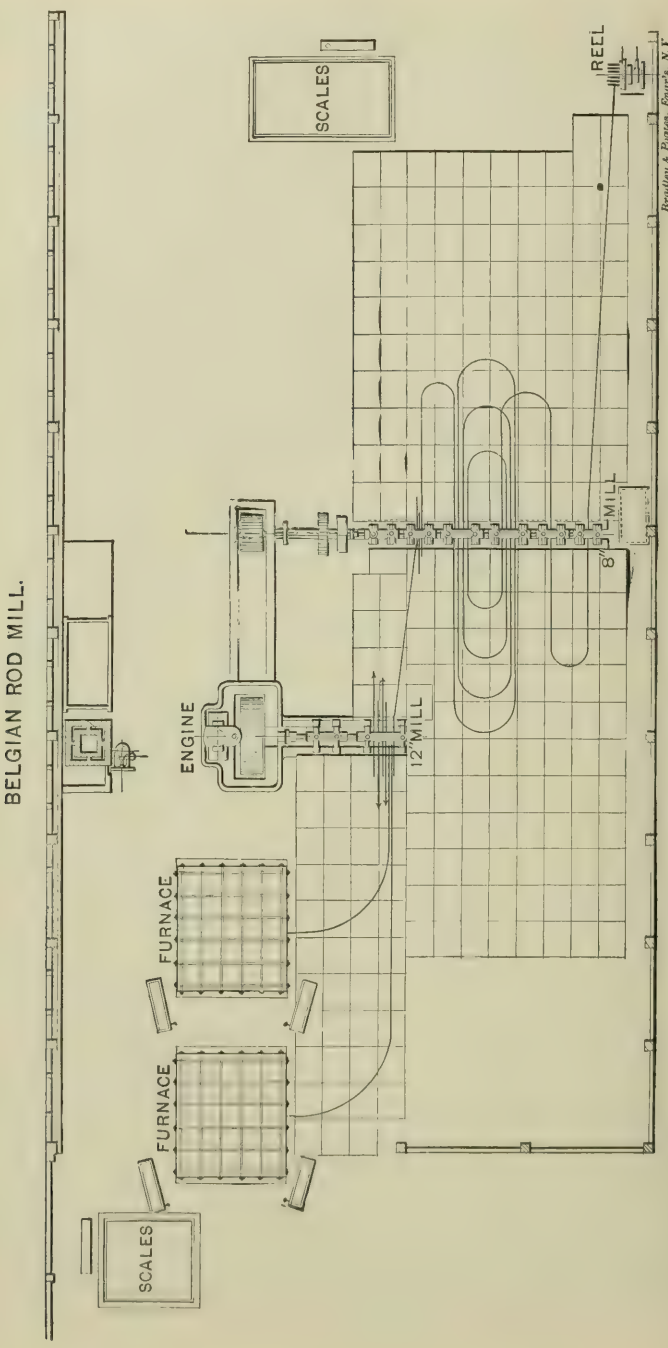

BELGIAN ROD MILL.
SCALES
REEL
Bradley & Pearse, Engr's, N.Y.
8" MILL
12" MILL
ENGINE
FURNACE
FURNACE
SCALES

FIG. 217.

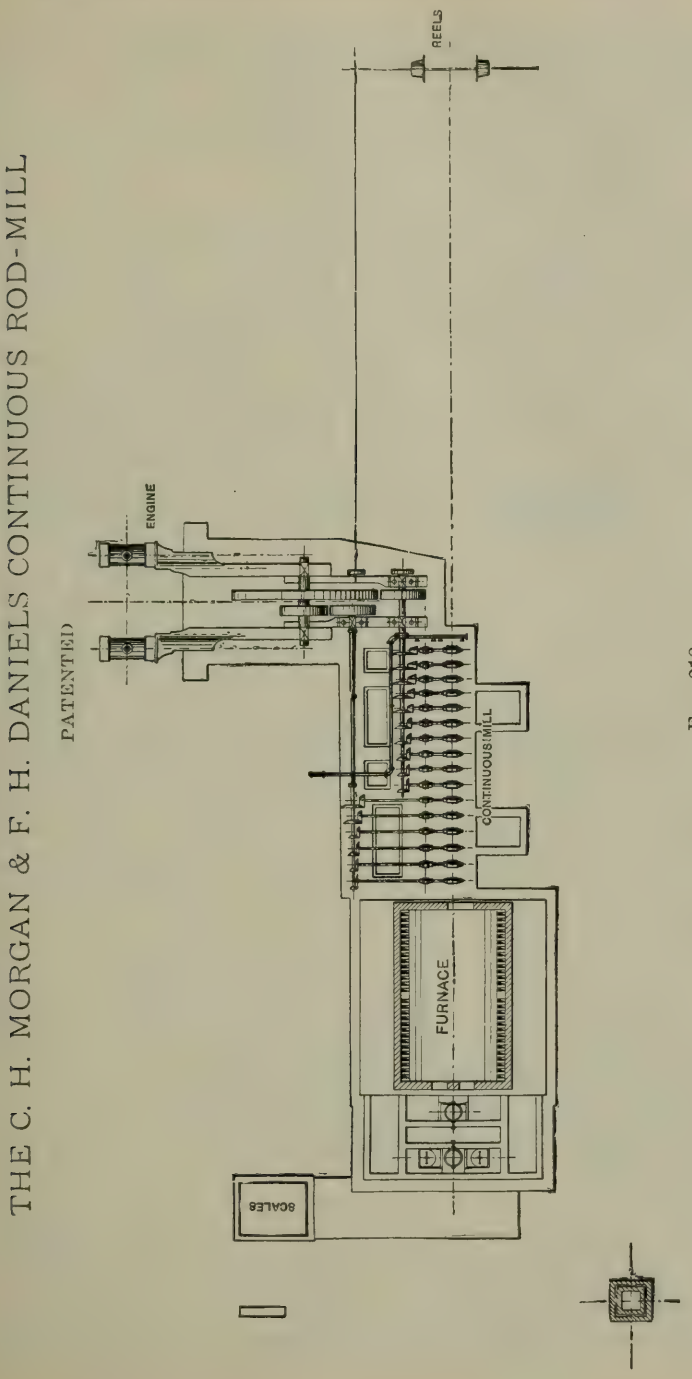

THE C. H. MORGAN & F. H. DANIELS CONTINUOUS ROD-MILL
PATENTED
ENGINE
REELS
CONTINUOUS MILL
FURNACE
SCALES

Fig. 218.

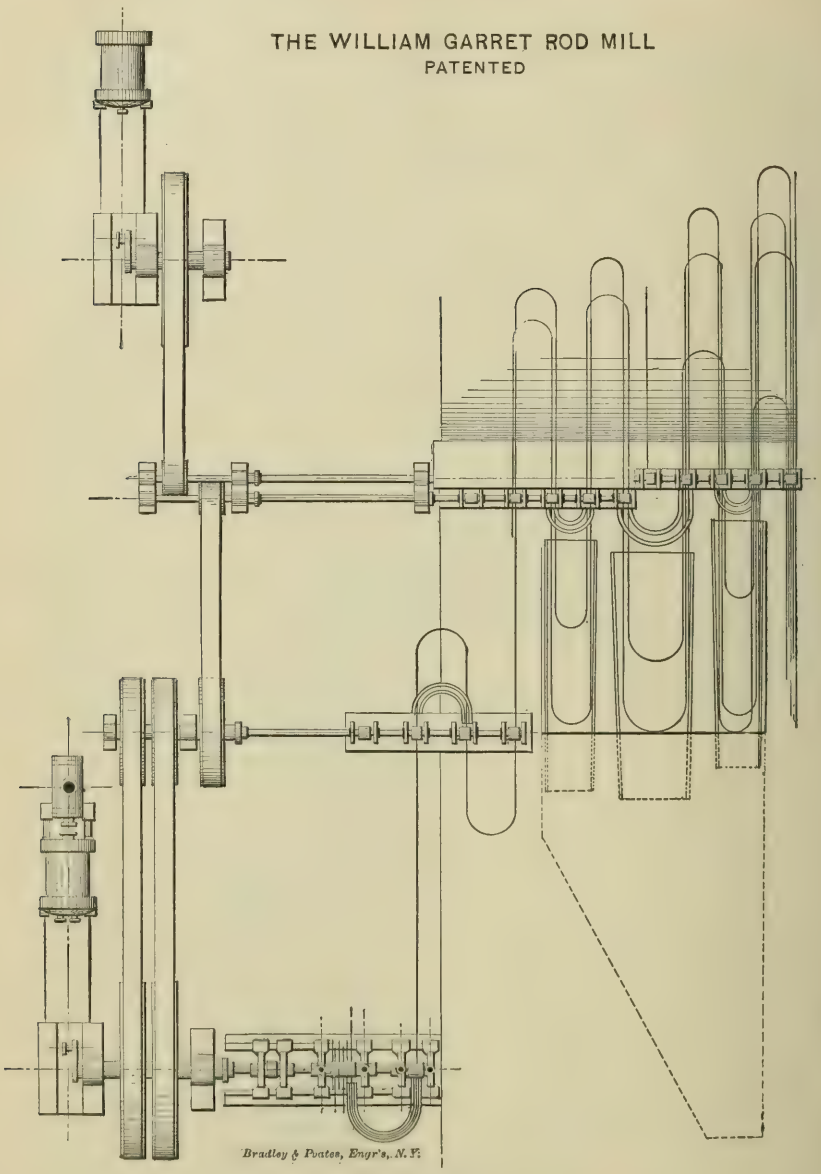


FIG. 219.

rolled in this country, and the credit for its development to the position of largest producer of wire rods belongs to our highly esteemed and honored member, William Garrett.

The credit of the introduction into America of the second

system or continuous method of rolling belongs to the late Mr. Ichabod Washburn. The credit for its development afterward must be divided among the engineering corps of the Washburn & Moen Manufacturing Co., Mr. Chas. H. Morgan and the writer having taken a somewhat prominent part in such development.

Of course there are mills which vary in a slight degree from the two systems, but in all cases the difference consists chiefly in combining the parts of the rolling mill plant, so that they are arranged to accomplish the same results, by substantially the same mode of operation.

The Garrett Rod Mills (Fig. 219) were introduced very rapidly as soon as the successes attained by Mr. Garrett were made public. The first mill was erected in 1882 by the Cleveland Rolling Mill Co., the annual capacity being 45,000 tons. Other mills were erected in the following order:

Cleveland Rolling Mill Co., 1st mill	1882, 45,000	tons per year.
Hartman Steel Co	1883, 60,000	" "
Oliver & Roberts Wire Co	1884, 60,000	" "
Braddock Wire Co	1885, 45,000	" "
American Wire Co	1886, 60,000	" "
Joliet Steel Co	1889, 50,000	" "
American Wire Nail Co	1890, 45,000	" "
Newcastle Wire Nail Co	1891, 45,000	" "
Iowa Barb Fence Co	1891, 45,000	" "
H. P. Nail Co	1891, 45,000	" "
Kilmer Manufacturing Co	1892, 30,000	" "
Cleveland Rolling Mill Co., 2d rod mill	1892, 30,000	" "
Pittsburgh Wire Co	1892, 40,000	" "
Total annual capacity	610,000	" "

Maximum output in one turn, Beaver Falls, No. 3 rods	349,460 lbs.
Maximum output in one turn, Joliet, No. 4 rods	342,620 "
Largest single turn, No. 5, Beaver Falls	322,000 "
Largest single turn, No. 5, Joliet	314,000 "
Largest year's work, Joliet, 1891	56,769 gross tons.
Maximum output, No. 3, in double turn, 10 hours each, Beaver Falls	277 "
Maximum output, No. 4, in double turn, 10 hours each, Joliet	307 "
Maximum output, No. 5, and coarser, in one month, Beaver Falls	5,724 "
Maximum output, No. 5, and coarser, in one month, Joliet	5,462 "

The rod-rolling capacity of the United States I estimate as follows:

Garrett System, running at maximum capacity.....	650,000	gross tons.
Continuous system, running at maximum capacity ..	250,000	"
Other forms of mills running at maximum capacity .	100,000	"
	1,000,000	"

Although the above figures are undoubtedly a conservative estimate of the annual capacity of the rod-rolling mills in the United States, we have not been able, up to date, to actually obtain this output, on account of the inability to continuously run rod-rolling mills throughout the year. Repairs and other stoppages largely curtail the maximum output.

Mr. Swank, of the American Iron and Steel Association, in his last report, places the total production of wire rods for the year 1892 at 627,829 gross tons, against 536,607 tons in 1891, an increase of 91,222 tons. Pennsylvania made the largest quantity in 1892, Ohio second, Massachusetts third, and Illinois fourth. Nearly two-thirds of this entire output of wire rods was consumed in the manufacture of barbed wire fencing and wire nails.

Probably no one in the United States has overcome more obstacles in rod-rolling than William Garrett. Commencing with an output of 70,000 lbs. in ten hours, the Garrett mill now produces as high as 349,000 in the same time. This has been brought about by being constantly on the alert to increase the output every time the possibility of producing this result presented itself.

Shortly after adopting the power reel, Mr. Garrett conceived the idea of finishing two rods simultaneously and reeling them on independent power reels. This innovation was a complete success, and to-day it is the common practice to finish as many as five at a time, the mill, of course, being supplied with five or six reels for coiling the product.

In addition to the increase in product by multiple rolling, Mr. Garrett quickly perceived the advantages of the McCallip repeater for conducting the first end of the square section from one groove to the next, thereby dispensing with about one-half of the catchers, reducing the cost of rolling, and increasing the efficiency and output of the mill, also permitting an increase in weight of billet to 150 lbs.

The writer was well acquainted with Mr. McCallip and saw the repeater in operation at Columbus, Ohio, in a mill of which Mr. McCallip had charge, and Mr. McCallip deserves the credit of having invented the device which has had more to do with the development of the looping system of rod-rolling than any other. There have been several devices suggested by others to accomplish this result, but to-day the McCallip repeater is the one in general use in the United States on all looping mills. McCallip's patent was taken out October 23, 1877.

Automatic reeling was used experimentally at the works of the Washburn & Moen Manufacturing Co. as early as 1879, and put in successful and constant operation in 1886, and is now exclusively used in all wire-rod rolling mills in this country.

As the maximum output of all rod-rolling mills depends, of course, upon the capacity of the reeling apparatus, the old-style reeling apparatus, that is, the power reel and the large iron floor, will now be explained more fully by the following example:

In 1878 the wire rods rolled by the Washburn & Moen Manufacturing Co. were the product of a continuous mill; that is, a rolling mill made up of a number of pairs of rolls so arranged that the hot billet passed from the first to the second, from the second to the third, and so on. As the billet was reduced in cross sectional area by each pair, it was necessary to give the second pair a surface speed much greater than the first pair; and the third pair a still greater surface speed; the final pair requiring a surface speed of almost thirty feet per second, faster than a mile in three minutes.

The first end of the hot wire rod issued from the final pair of rolls over a large floor of iron, and the wire rod, as it issued from the rolls, was flirted in loops over one side of the iron floor, when a nimble attendant ran upon the floor, seized the first end with his tongs, and thrust it through a hole in a screen of plate iron and between the fingers of a reel. As soon as the first end of a hot wire rod was connected with the reel, an attendant set the reel in motion and rapidly quickened its speed until the loops of the hot iron rod were taken off the iron floor, and the hot rod extended in a long sag from the reel to the final pair of rolls; when the speed of the reel was carefully regulated to take the rod about as fast as it was delivered by the final pair of rolls. This reel can be well named a traction reel; that is, it

pulled the hot rod first from the iron floor and then kept it under strain between itself and the final pair of rolls. In this and all other traction reels, the speed of the reel must be regulated with great nicety during the whole operation. With this

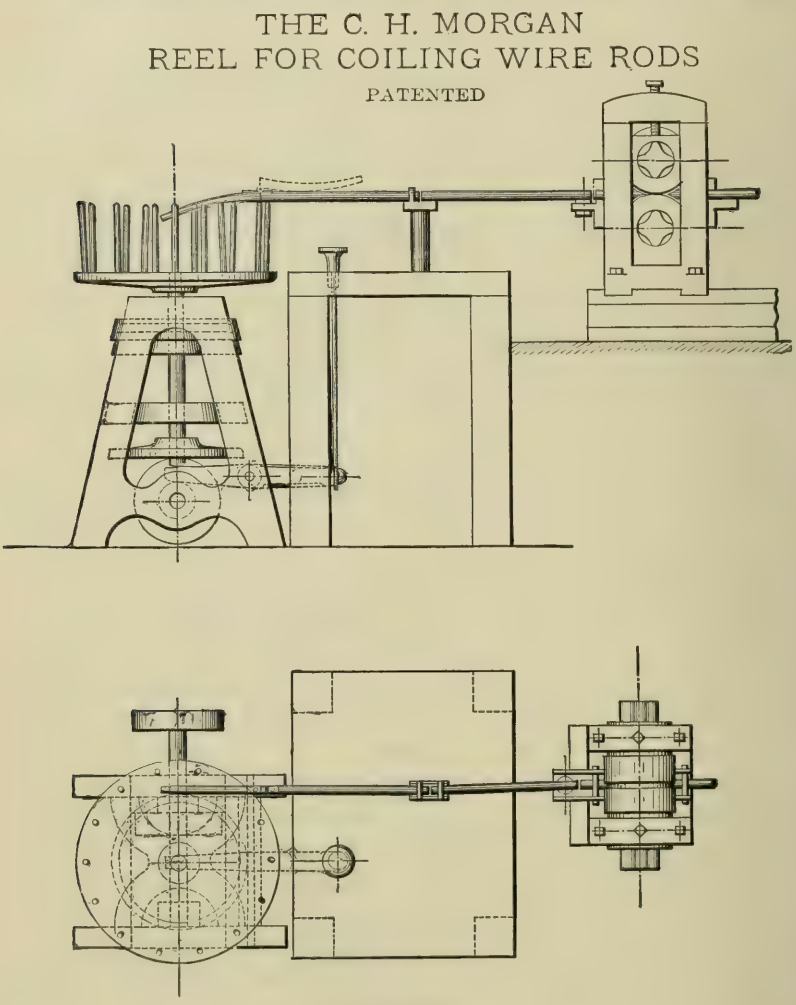


Fig. 220.

system of rolling, 600 revolutions was the maximum speed in continuous mills, rolling one rod, and 450 revolutions on the looping system, rolling two rods.

In order to increase the output, the speed of the final pair

must be increased, or the number of rods rolled at the same time must be increased. The first is practically impossible, because the traction reel is not adapted for any greater speed, and the second is objectionable because it requires a traction reel with its large floor for each rod.

With the automatic reel, the former limits of speed of the final pair of rolls, and the former limitations as to the number of rods, have disappeared; for the iron floor and traction reels

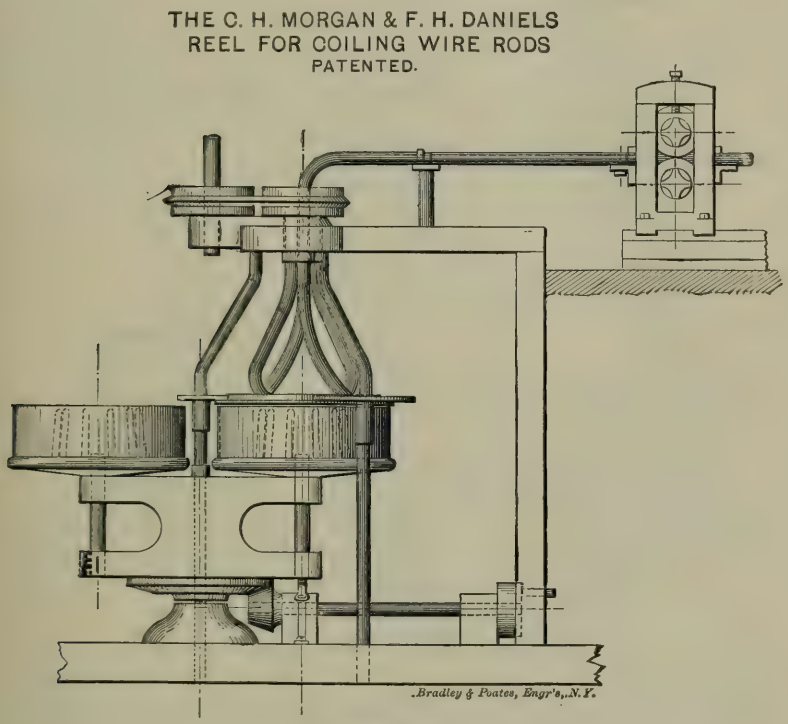


FIG. 221.

are abolished, and the automatic reels can be set so near the final pair of rolls that the hot rod passes directly into the reel while the reel is revolving rapidly.

Automatic reels may be divided into two kinds, pouring reels and direct-acting traction reels. The pouring reel is either a receptacle in rapid revolution into which the hot rod enters through a stationary pipe, or a conductor pipe in rapid revolution, delivering into a stationary receptacle, the rod seeking in

either case automatically that part of the annular bottom portion of the reel receptacle which suits the speed of the rod.

The direct-acting traction reel is a pair of disks working at the proper speed and adapted to seize the first end of the hot rod as it issues from the finishing pair; the surface speed of the reel being regulated by slip of the belt, to suit the speed of the rod.

These improvements in automatic reeling were patented by C. H. Morgan and F. H. Daniels, February 24, 1880, two patents; C. H. Morgan, one patent, February 24, 1880; F. H. Daniels, November 19, 1889, one patent; the application for this patent having been filed in 1886. These inventions are

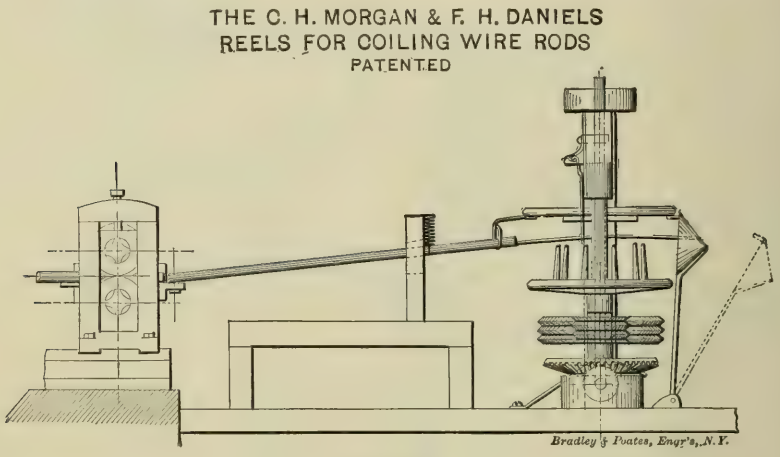


FIG. 222.

illustrated on Figs. 220 to 223. These four inventions were the first on record to illustrate fully the principles of automatic reeling now in use. One system seizes the wire rod by means of two plates coming together; in other words, a direct-acting traction reel (Fig. 222) with a mechanical seizing device; and the other three, pouring reels, into which the product pours and is coiled without being attached to the reel.

The pouring system is accomplished in two ways: first, by the rotating pipe system, which acts as a conductor for the wire rod, throwing the rod into circular loops, which are deposited on a stationary receptacle (this is the Morgan & Daniels system of reeling, Fig. 221); second, the stationary guide pipe, which conducts the hot wire rod to a rotating receptacle, which, in the

Morgan invention, is an annular space formed between two vertical rows of pins (Fig. 220), and, in the Daniels invention (Fig. 223), a tub with an inner row of pins. (This last, although the application for patent for it was not filed until 1886, was invented early in 1878.)

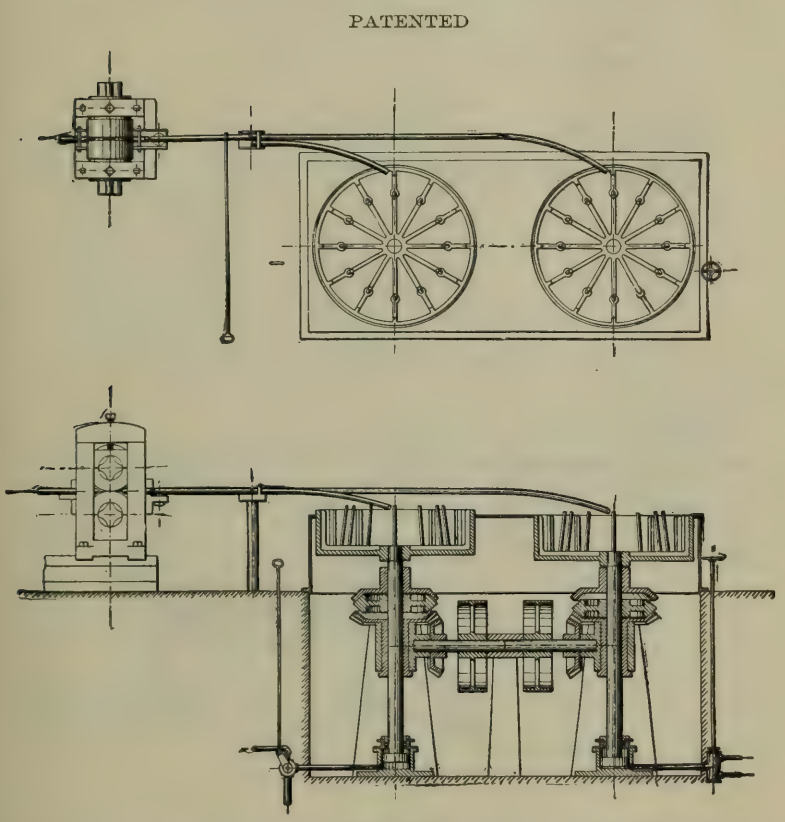


FIG. 223.

But all of these inventions lacked one device to make them a practical success. None of these reels were supplied with means for removing the completed coil from the reel. Early in 1878, I invented a system which is now used in all of the reels of the Washburn & Moen Manufacturing Co. and in several other mills. (Fig. 224.) Application for patent for this invention was

not filed until 1886, and after a warmly contested interference suit, which was decided in my favor, the patent was issued February 3, 1891, No. 445,965.

The invention consisted in combining a spider or lifting plate with the tub reel, the first end of the rod being deposited by the guide pipe upon the annular lifting plate or movable bottom

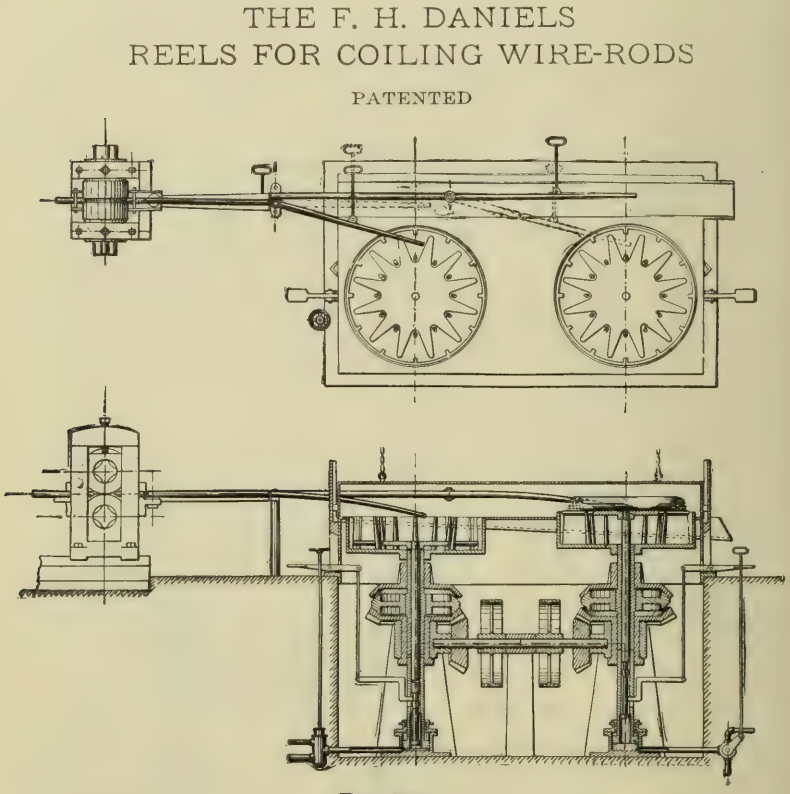


Fig. 224.

of the reel, whose surface speed varies, being more rapid near the outer edge and slower near the inner edge, and greater and greater from the inner edge outwards. For this reason the first end of the wire rod first strikes a horizontal surface whose surface speed is greater than the speed of the rod, for the first end of the rod shoots across the annular surface of the lifting plate or spider, and rests upon the outer edge of the annular plate; and the friction of the first end of the rod on the lifting plate

and the rapidly revolving rim or outer wall of the reel causes the rod to be coiled up between the rim or outer wall and the inner circle of spokes concentric with such outer wall or rim. This, together with the beautiful adaptation of the contrivance to the varying speeds of the rod, are the most striking features of the invention, for although the speed of the reel is constant, yet when the wire rod is pulled on—that is, called for faster than the final pair of rolls deliver it—it instantly moves nearer the centre of the rapidly revolving annulus, and finds a circle whose surface speed suits it; or if the rod is delivered faster for a moment than the surface speed of the circle of the annulus which supports it, it instantly moves farther away from the centre and finds a new circle whose speed suits it.

The speed of the wire rod as it issues from the final pair varies a few feet a second from time to time: but these variations of speed of the rod are all automatically cared for, although the speed of revolution of the reel (and of the annulus, which is the lifting plate or movable bottom of the reel) is constant.

Mr. Garrett perfected the direct-acting traction reel in 1888, patented it in 1889 (Fig. 225), and the reel is in successful operation at the Joliet works, although this reel is on the same principle as the Morgan & Daniels reel. All the other rod mills in the United States are using the Morgan & Daniels pouring reel, and largely the rotating pipe, with various devices for removing the coil from the receptacle, and in many cases using the Daniels discharging lifting plate.

To be sure, many of the pouring, rotating, pipe reels introduced differ in construction somewhat from the Morgan & Daniels plan, but in all cases the pouring principle is involved, the coil being formed either by rotating a pipe or conductor or by rotating a receptacle. Both of these plans were fully tested and developed experimentally at the Washburn & Moen Manufacturing Co. Works early in 1879.

The continuous system of wire-rod rolling was greatly improved and put on a more paying and satisfactory basis in 1879 at the works of the Washburn & Moen Manufacturing Co. The writer was then connected with Mr. Morgan in the construction of a continuous mill, having all horizontal rolls. (Fig. 218.) The Bedson mill was difficult to keep in order, on account of half the rolls being vertical. On the mill, as built in 1879, several joint patents were taken out by us.

Immediately after the completion of this mill we constructed a second one, in which eight of the pairs were continuous and six looping. Both of these mills produce as high as 110,000 lbs.

Mr. Garrett has so rapidly increased the output of wire rods

THE WILLIAM GARRET REEL
FOR WIRE RODS
PATENTED

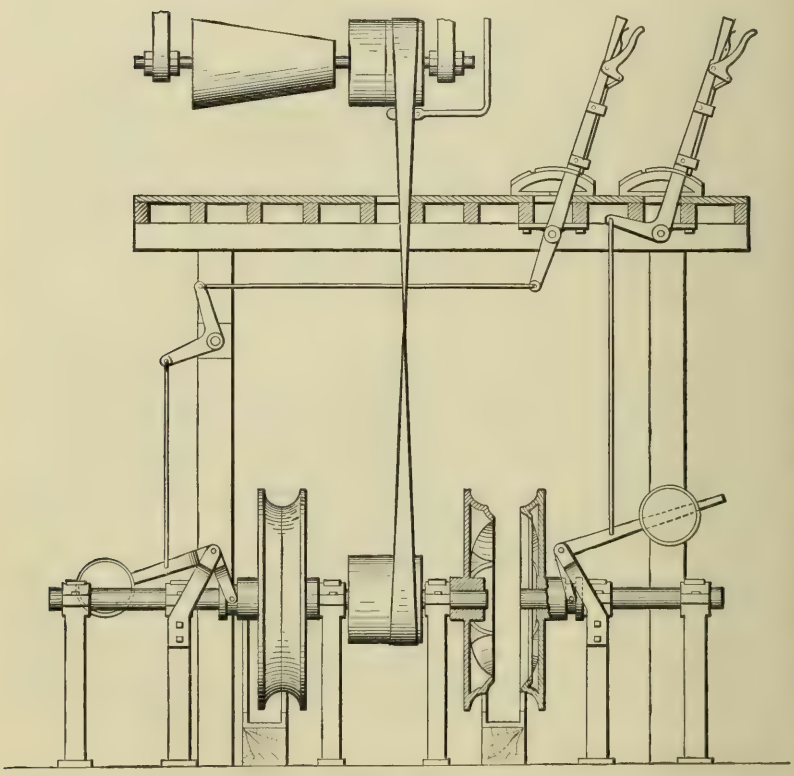


Fig. 225.

by finishing several rods at a time, that the output of the continuous system became quite insignificant, he having set a pace difficult to follow. In order to increase the output by the continuous system, between 1883 and 1887, I perfected and applied for patents on a rod-rolling mill, using billets of 200 lbs., 4 inches square, rolling the billet in a first mill from 4 inches to $1\frac{1}{8}$

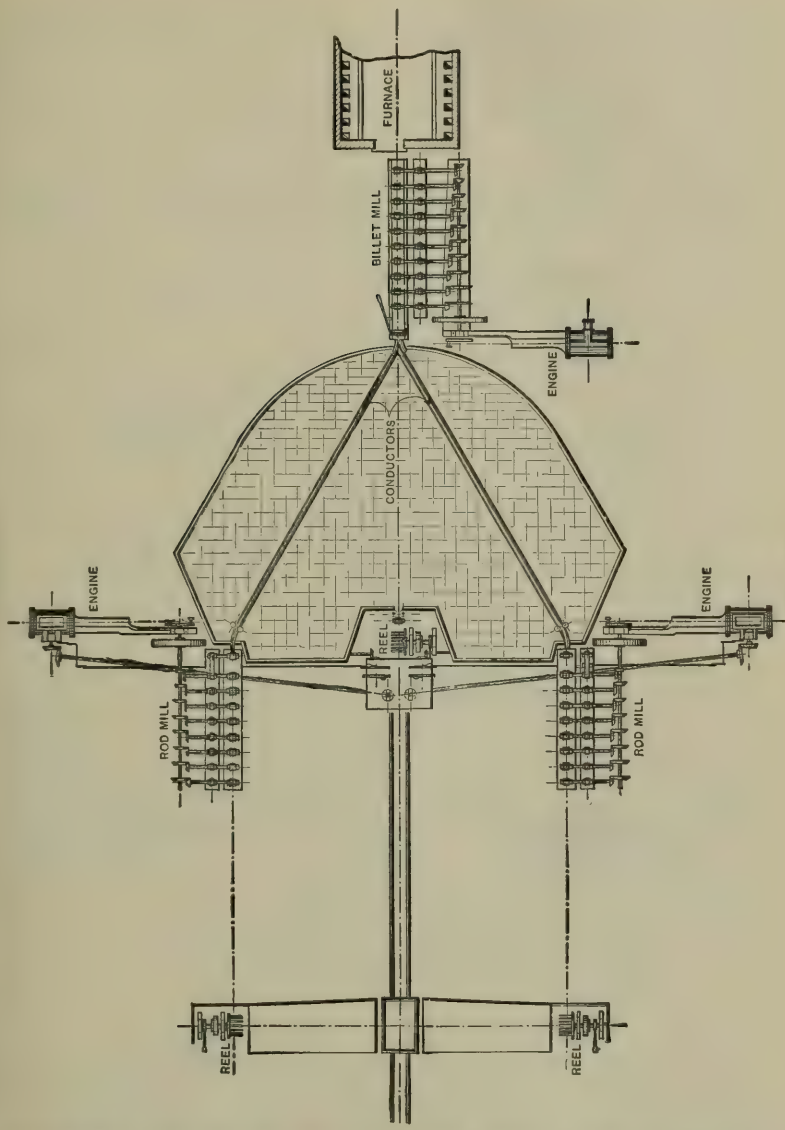


FIG. 226.

THE F. H. DANIELS WIRE ROD ROLLING-MILL PATENTED

inches, and finishing the product thus formed in several finishing mills. (Figs. 226 and 227.)

Although it has been suggested by others to finish the product of one train in several finishing trains, they all lacked facilities for making the operation continuous and for handling the product mechanically. This system was patented in 1884, 1886, and 1887,

in several patents, and, after extensive litigation, Patent No. 440,-696, dated November 18, 1890, was issued to me, on application filed September 8, 1887. This plant is now used by the Washburn & Moen Manufacturing Co. and the American Wire Co., Cleveland, Ohio.

After perfecting for the Washburn & Moen Manufacturing Co. their large rolling-mill plant at Quinsigamond, the opportunity

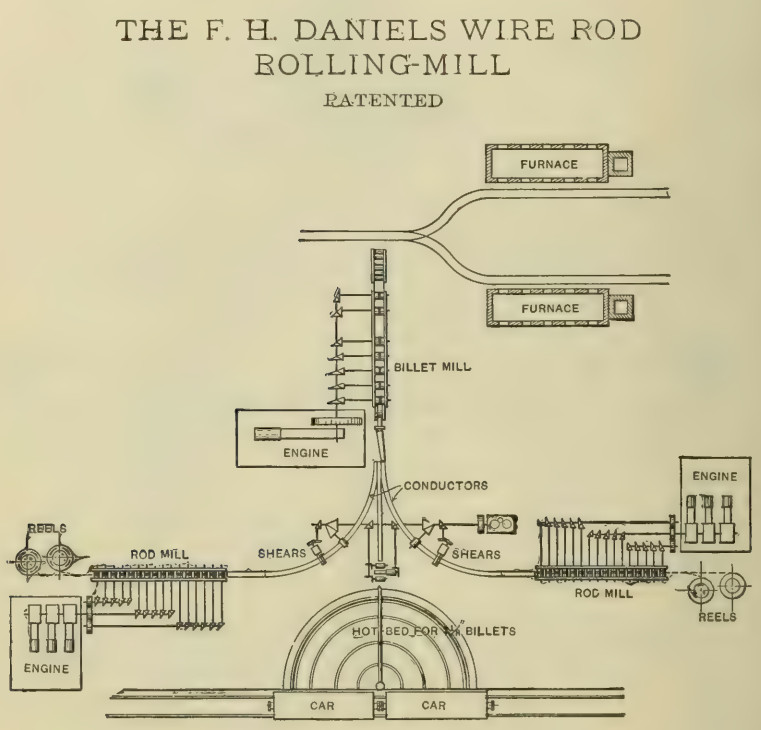


Fig. 227.

was presented to build for them a plant at Waukegan, Ill. In 1886 the output of their Quinsigamond mill was 40 tons in ten hours, of No. 6 or No. 8 rods. The output to-day exceeds 200 tons in the same time, and for one week has been as high as 2,500 tons.

Both the Quinsigamond and Waukegan rod mills are adapted to switch the product of a train of rolls to either one of several conductors, having guiding and controlling walls to prevent the product from escaping sidewise, or buckling, and to deliver the

product from the conductors by means of feed rolls. Its very great value and importance is in rolling large billets, 4 inches square by 4 feet long or longer, into billets of much greater length and smaller cross section; the smaller billets in practice being a little over one square inch in cross section and about 60 feet long, and these smaller billets are rolled into wire rods and coiled by an automatic pouring reel.

In practice it is easy to speed a primary train so as to produce several times as many wire-rod billets as a single secondary train can roll into wire rod. This system is illustrated in Figs. 226 and 227.

It has been the universal practice in continuous mills to roll only one line of metal at a time. It has often been suggested to roll two, and Bedson went so far as to take out a patent for such a system, but never went beyond. In 1891, when it was decided by our company to build their new plant at Waukegan, we determined to undertake multiple rolling continuously, and we are now successfully rolling as high as four lines simultaneously, with an output of 400 long tons in one day of two ten-hour shifts, or 2,000 tons a week.

Few rod rollers appreciate the difficulties of continuous rolling; the skilled attendants necessary, combining rare mechanical ability with good rolling-mill judgment, the very delicate adjustment necessary to compensate for the differences in increase in lengths, on account of slight variations in heat and chemical compositions of the steel, the long train work of gearing to maintain and keep in order, running, as it must, at a very high rate of speed (as high as 1,200 revolutions a minute), all conspire to render the problem a very perplexing one. We have often been so discouraged as to be on the point of discarding the continuous system and going back to the looping system, but further successes always gave us new courage. We have, however, advised our friends to put in the Garrett system, and when Mr. Wellman, the well-known member of this Society, asked us several years ago to advise him regarding the best rod mill for the American Wire Co. to install in their plant, *i. e.*, whether the Garrett or continuous system, we advised that, taking everything into consideration, including the expense of the mill and the skilled attendants necessary, the Garrett mill would probably best suit them, and the advice was followed. Later they put in, under Mr. Morgan's direction, the continuous system

with automatic reels, but we have been informed that they never regretted having put in the Garrett mill, which produced nearly double the output of the continuous system, as installed by them.

Our people, however, are well suited with their mills at Worcester and Waukegan. To be sure, the continuous rod is not as nearly round as a Belgian rolled rod, and there is about one per cent. of croppings, on account of finny ends, which is a defect incident to all continuous mills, but the looping mill makes more scale. Taking everything into consideration, the cost of rolling is about the same on both systems, and the percentage of good rods produced about the same.

In summarizing this sketch of the development of wire-rod rolling in this country, it would seem that the first advances, say from 1876 to 1886, were due mainly to two causes : the first being the quality of the metal used, and the second the fact that back-and-forth rolling was abandoned and the first end of the billet was kept constantly moving forward at a constantly increasing speed. These two causes in about ten years so increased the output that the reeling apparatus in use before 1886 was incapable of reeling the output, and the advance since 1886 has, in my judgment, been mainly due to automatic reeling.

DXXIX.*

A FARE-INDICATOR AND RECEIPT-CONTROLLER, OR THE "TAXAMETER" AND "COLUMBUS."

BY C. PIEPER, HAMBURGH, GERMANY.

THE objects of this apparatus are twofold:

1. It indicates to the passenger, in one figure, the fare he has to pay for the use of the carriage.

2. It shows to the owner, in one figure, at the end of a day's work, the whole amount of the daily earnings made by the driver.

The attainment of these objects is of equal advantage to the public, the authorities, and the owners of livery carriages.

The *public* avoids thereby the difficulty of interpreting unknown and complicated tariffs, as well as disputes with the coachman, which in all large cities are felt as a nuisance, especially by strangers, but often enough by the inhabitants as well, and even detain them from hiring a cab, if they are not obliged to. As the passenger can read from the apparatus exactly what he has to pay, the frequent overcharges by the drivers are completely avoided.

For the *authorities* the introduction of the apparatus is desirable, because they will be no longer called on to decide in cases of differences between the public and the hackmen, and a great number of complaints will cease to be brought before them.

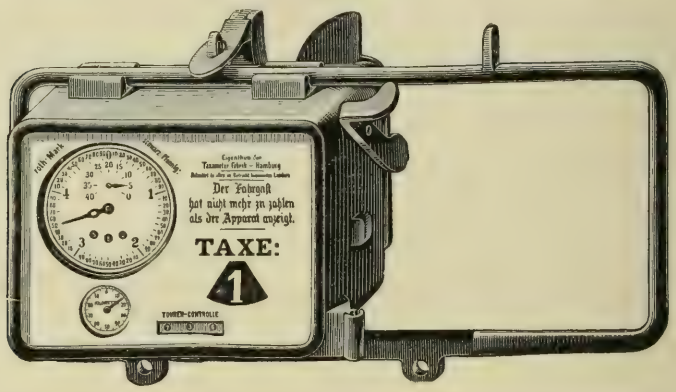
Finally, the *owner* of the carriage obtains an apparatus which has been long called for, by which the owner is able to control the receipts of the drivers. He can read them off from the apparatus in one figure, at any time and for any period, and is thus protected from being defrauded by the drivers.

The demand for fare-indicators is at present before the attention of all large cities in Europe. Paris has been longest in seeking for a solution of this question, and it is some time since the municipal authorities made it compulsory for all cabs to be provided with a fare-indicator. But until now none of the sys-

* Presented at the Chicago meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

tems introduced in Paris, nor those invented and tried in Berlin, Brussels, and other places have given satisfactory results.

The only fare-indicators which have proved perfectly reliable in practice are those manufactured by the taxameter factory * in Hamburgh. These apparatus have been successively introduced in Hamburgh and Bremen, and since January last in Berlin also, and have met with very good success. The leading cab companies and many other large firms of this trade have provided their carriages with this system of indicators, the introduction of which is very much appreciated by the authorities and the public. In Hamburgh the police authorities have made the use of it compulsory for all cabs submitted for new licenses.



FRONT VIEW OF FARE-INDICATOR AS USED IN HAMBURGH, GERMANY.

FIG. 228

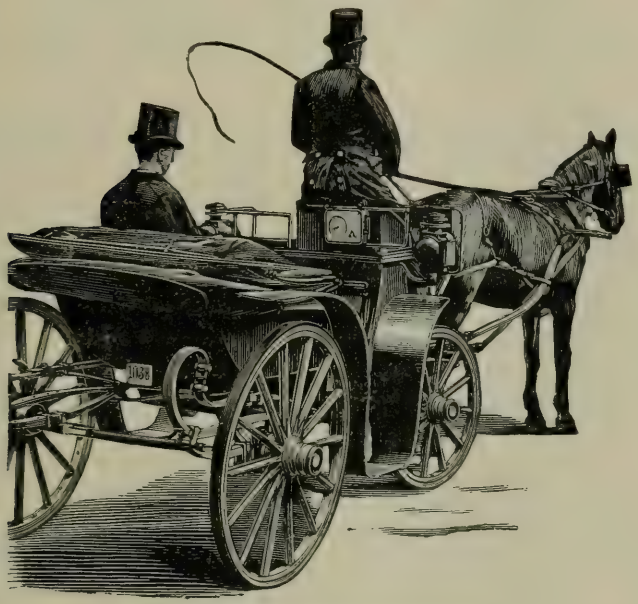
These indicators may be built to comply with the current money of any country of the world, and to suit any proposed tariff of fares.

The motion of every apparatus may easily be changed to suit variations in the rate of fares. If, for instance, the standard fare is charged for conveying one or two passengers at day time, the driver is enabled by the action of a lever to raise the fare 33 or 50% in case three or four passengers are conveyed, or if some heavy trunks are carried, and to raise it 100% for a ride at night time or to places beyond the city limits. These variations in the schedule of fares may be fixed according to any other figure, and the mechanism set accordingly. The rate of fare at the

* Westendarp Pieper.

time governing the motion of the apparatus is marked by the appearance of a corresponding figure visible to the passenger. No matter how often, or in what succession the various rates are thrown in, both the total amount to be paid by the passenger for a single ride, and that received by the driver during a whole day or any period, will each be indicated in one figure.

When looked at from the seat of the carriage, the apparatus exhibits a large dial, on which, instead of hours and minutes,



CARRIAGE WITH FARE-INDICATOR.

FIG. 229.

the fare to be paid by the passenger is indicated by the pointers. The figures for the larger coins, like marks, florins, shillings, dollars, francs, lires, crowns, rubles, etc., are printed in red, while those for the smaller coins like 10-pfennigs, kreutzers, pence, cents, centimes, oeres, kopeks, etc., are in black. The large dial is arranged to indicate the fare for a single ride up to 5 marks in German coinage, while the golden hand advancing on the small dial shows the additional amounts from 5 to 50 marks. Thus, if the large hand stops at 1.50 marks and the golden one at 10 marks, the total fare to be paid is 11.50 marks.

A figure which appears in an aperture at the lower right-hand corner—like No. 1 in the above view—indicates the rate of fare for the time governing the apparatus through the action of the driver. For instance, No. 1 may be meant for one or two persons by day time, No. 3 for night fares between specified hours, etc. A printed tariff suspended from the apparatus explains these variations of rates, and the figure indicating the rate is shown in a bright, distinct color, and visible to the passenger in the carriage, whether open or closed. The leverage by which this change of rates is effected influences the hand of the dial in such manner that with a higher rate of fares the hand is made to travel faster.

The apparatus not only indicates the charges to the passenger according to the tariff, but shows also, on a special "receipt-controller," the total of the amounts received by the driver in the course of a day or so; and a second dial registers the number of trips made in the same period. Thus the owner of the carriage is enabled to read off at a glance how much the driver has earned during the day, and by how many single rides he has earned it.

The apparatus is of the size of an ordinary cigar-box, and is enclosed in a metal box measuring about 9 x 7 x 3 inches, which closes perfectly tight, so that neither moisture nor dust can enter, and is absolutely inaccessible to the driver, the passenger, and even the owner of the carriage, a seal and stamp insuring sole access for the manufacturer or his representatives.

The apparatus, which is mounted on a simple guide bar, may be fixed to any sort of open or closed carriage, without any alteration, ready for use within an hour or so, and can be replaced by another one in a few minutes.

During the use of the carriage the apparatus is always before the eyes of the passenger. To effect this on four-wheeled carriages, it has to be moved towards the center of the driver's box before being put in operation, while on a two-wheeled carriage (a so-called hansom) the apparatus is moved to the right-hand side of the driver's box.

When the ride has been finished, and the driver has received the fare, he will hasten to stop the mechanism, in order to prevent the hand from advancing farther and thereby registering on the "receipt-controller" a larger amount than the driver actually collected. To put the fare-indicator out of action, the apparatus has to be moved to its former position on the guide-

bar; that is, to the right when used with a four-wheeled carriage, and back towards the driver when with a hansom, after which a signalling arm has to be raised. This signalling arm is provided with a little metal plate in shape of a flag, painted red and white, and bearing the inscription: "Frei" (Disengaged). It is only after these operations that the driver is enabled to put the mechanism out of action by the use of a simple and convenient lever, while the pointer on the dial, though stopped in its movement, remains in its position, in order to allow the passenger to read off at his ease how much he has to pay. By a plate visible through the aperture, close to the dial, and bearing the inscription "Cassa," or "Cash," the passenger is invited to pay his due fare.

After the fare has been paid and the carriage disengaged, the driver, by means of another lever, causes the dial to be partly covered by a red disk bearing an inscription to indicate that the apparatus is out of action.

The raised position of the signalling arm and the wrong position of the apparatus on the driver's box make it practically impossible for the coachman to drive with passengers without previously putting the indicator into action. For both the public and the police agents would see at a glance that the carriage was being put to an unlawful use. At night a lantern with colored glass is used for the same purpose.

As long as the "out of action" disk is visible, the driver is not allowed to refuse a desired ride, except when he is on his way to a place of appointment by previous engagement, or going home to the stable in case the horse is in want of rest. In these cases he covers the plate of the signalling arm, while on his way, by a blue disk bearing the inscription: "Bestellt," or "Ordered;" when stopping at the carriage stand, however, he is not allowed to use this cover.

When a carriage is engaged by a passenger, the driver has to shift the apparatus to the middle of his box—or close to the window when with a hansom—and has to lower the signalling arm. Both of these operations are impossible, however, before the arm, which is firmly locked by a catch, has been disengaged by means of a special device, the operation of which causes the fare-indicator to enter into action immediately. The hand on the dial then points directly to the initial fare, the "out of action" disk disappears, and a new trip is registered on the counter.

There are two kinds of fare-indicators built. One of them, called the "Columbus," is based on the principle of a time-tariff, and operated by a clock-work, which has proved reliable and durable in several years' practice. The other apparatus, called the "Taxameter," works both by time and by distance traversed, being actuated, while in motion, by the rotation of the hind wheel of the carriage, and by a clock-work while out of motion.

Below the hind axle there is a small air-pump suspended, the piston of which is pressed against the hub of the wheel by means of a spring. The hub being provided with an eccentric, or cam, acts against said piston at every rotation of the wheel, and produces a compression in the air pump. This impulse is transmitted through a strong and well-protected hose, leading along the vehicle up to the indicator, and capable of following the motion of the carriage springs. By this means every rotation of the hind wheel is made to move a bar provided with a pawl-lever, which acts on the cogs of a ratchet wheel, moving it on, and thus, by the agency of intermediate gearing and levers, actuates the hand of the indicator dial.

In the manner thus described in outline, the distance travelled by the carriage while in motion is measured; but as soon as the vehicle stops, the time-work mentioned above immediately begins to actuate the pointer, the details being so arranged, that, while both agents act on the same gearing, that only which travels fastest takes effect in moving the pointer.

In this way the taxameter is made to charge both prices—for the actual ride according to the distance passed over and for the stops according to the time, adding automatically these various charges, and showing directly in one figure on the dial the amount to be paid.

The rate regulating device is so arranged as to increase the speed of the pointer, recording higher charges the higher the rate of fare that is made to govern the apparatus. But it is only while the carriage is actually moving, and not during stoppages, that this increase in the rate of charges is effected the intention being to raise the charges only for an increase in the work done by the horse while driving, such as the transportation of more than two persons or some heavy baggage, but not while the carriage stops and the horse is at rest.

Below the dial there is a special distance indicator showing

the number of kilometers or miles passed over by the carriage with and without passengers, from the time of leaving the stable to its return, thus enabling the owner to regulate the amount of food and time of service according to the work done by his horse. The exact record given of the whole day's work gives him the best means of judging of the work done by driver and horse.

If, by order of the passenger, the carriage moves on rather slowly, as is frequently the case with strangers making a round trip through a foreign place, the fare charged by distance would be unreasonably low, owing to the very slow rotation of the wheels. But in this case the action of the time-piece exceeds that produced by the carriage wheel, and thus keeps the fare at a proper level during such slow rides.

The taxameter used at first to be placed inside the driver's box, and put to action by means of a special key, differing for every single apparatus. The improved style, however, as well as the "Columbus" apparatus, is mounted on a guide bar at the back of the driver's box. The handling of it is done by means of a lever, in a manner very simple and convenient to the coachman, yet so that he cannot operate the indicator, throwing it into or out of action, or changing the rates in the way he might wish to do, but only in the prescribed manner.

Wherever these fare-indicators have been introduced they have had the effect of materially increasing the tendency of the public to use hackney carriages, and resulting in a great improvement in the system for the public conveyance of passengers.

DXXX.*

IMPROVEMENTS IN THE ART OF CABLE-MAKING.

BY EMIL GUILLEAUME, MULHEIM, GERMANY.

THE art of cable-making has received an increased impulse during these last ten years, from the wonderfully extended application of electricity for telegraphic and telephonic service, for electric lighting and transmission of power, as well as from the growing necessity of placing the leads underground. The numerous patents which have been and which still are applied for, are the best proof of the attention given to this art. It would be going too far to discuss all the inventions which refer to improvements in cable-making; for the most part they are of very little, if any, practical importance, and of the few which have stood the practical test, only a small percentage may claim the character of a striking novelty.

The term "electrical cable" ought, strictly speaking, only to apply to an electrical conductor insulated and dressed or sheathed in such a manner as to have the appearance of a rope or cable and to coil like one; lately, however, this term has been extended to include insulated rods and tubes, such as the well-known Ferranti cable.

Every cable for the conveyance of electricity is composed of the cable-core (one or more insulated conductors) and the protecting armor or sheathing, and I will discuss these two principal parts of an electric cable separately.

THE CABLE-CORE.

The cable-core is composed of the conductor (leading wire) and the insulating covering.

The conductor may be formed of a single wire, or of a number of wires formed into a strand or rope. The wire or wires may be of circular, or of any other section; as a rule, it will be made of

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

copper of high conductivity, and only in exceptional cases, where besides conductivity a more or less high tensile strength is claimed, copper compounds (alloys) and steel are made use of.

Important progress has been made in the manufacture of copper wire of almost absolute pureness, and accordingly high conductivity. Whereas formerly one had to be content with copper wires with a conductivity of 90% of that of pure copper, we have now copper wire at our disposal which yields more than 100%; *i.e.*, purer than the copper Matthiessen considered to be pure copper, when he took it as his standard for determining the pureness and conductivity of copper leading wires.

Other notable novelties respecting the conductor are confined to the shape or section of the wire. Thus, my firm (Felten & Guilleaume, of Mulheim-on-the-Rhine) has been granted patents for telephone cables of low capacity in which the leading wires of the core are of a triangular, rectangular, or star-shaped section. The wire is twisted round its own axis, and the spiral grooves thus formed on the surface of the wire allow the insulating material to touch only the top edges of the grooves, the latter themselves forming air-spaces between the insulating material and the spirally wound sides of the wire. My firm also manufactures electric-light cables in which the conductor is composed not of round wires but of wires of segmental section, in order to do away with the empty spaces between the wires, and thus materially reduce the diameter of the core as well as the diameter, weight, and price of the cable. Others have for the same purpose proposed to deform the leading wire longitudinally, *i.e.*, instead of using straight wire to corrugate it or bend it into a zigzag: such proposals, however, can hardly be seriously considered.

The insulation or insulating material is the vital part of any cable, and yields the most fertile working field for the ingenuity of cable engineers. The claims on the properties of the insulating material are so manifold that it is often very difficult to combine them in one material. According to the use of the cable, whether for telegraphic or telephonic service, for electric lighting or transmission of power, more or less high claims are put on the insulating material as to the insulation resistance, the absence of static capacity, the prevention or reduction of the disturbing influence of induced currents, the tension resistance. The insulating material must preserve the claimed properties for as long a space of time as possible; it must not soften under the influence of heat, it must

not get brittle under the influence of cold; it must at all times and in any position of the cable retain the conductor in its central position in the core; it must, further, possess a given tensile strength, sufficient power of resistance against external pressure; the size and the weight may be of importance, and must be taken into consideration; also the price.

At the early stages of cable-making, when cables were without exception wanted only for telegraphic service, gutta-percha and india-rubber have been used exclusively, and gutta-percha continues to be the chief insulating material for submarine cables. The good properties of both are sufficiently known; however, with cables that are exposed to heat, and with electric-light cables, in which the conductor is apt to increase in temperature, one has to reckon with the drawback that gutta-percha is softened by heat, and that then the leading wire will sag out of its central position. Vulcanized india-rubber is less influenced by heat, but it is very costly, and the high price is the reason why gutta-percha and india-rubber are only used to a limited extent, in particular for electric-light cables with larger sections of copper conductors. For use in buildings, smaller leads, etc., pure india-rubber is also sometimes used with a serving of cotton or silk on the wire. Improvements in connection with gutta-percha and india-rubber have been principally carried out in the way of cleaning the raw material and in the covering machines, also in bringing out superior india-rubber compounds and new methods of covering the wires. India-rubber cores have usually two or three coverings of india-rubber; where there are three, a layer of pure Para rubber is applied next to the wire, then a second layer, termed the "separator," without sulphur, and finally the "jacket," with an addition of sulphur. Such cores, varying in composition and with different rubber compounds, are known in the trade as "hoopers," okonite-, kerite-, neptunite-cores, etc., etc.

The high price of gutta-percha and india-rubber compelled cable engineers to look for substitutes which might be had in any desired quantity at a reasonable price, and possessing the qualifications for the various purposes of application; viz., low capacity for telephonic purposes, and sufficient strength to withstand the effects of heat and high tension for electric-light purposes.

Numberless are the inventions made and the patents claimed in this direction. All of these deal with specially prepared mineral and vegetable oils, bitumen, resin, wax, etc., or mixtures of one or

more of these with other, preferably carbonaceous, substances. All of them are, however, more or less poor substitutes for gutta-percha or india-rubber; they do not possess the valuable tough elasticity, they either soften under the influence of warmth or get brittle under the influence of cold, or they shrink in time and crack, etc. The first great step forward in this direction was the employment of fibrous material in connection with the above substances, the wire being served with a winding or braiding of thread, or a wrapper of tape and finally of paper, and this serving being impregnated with one or the other or with mixtures of the aforesaid substances. The serving of thread, tape, or paper retains the wire in its central position in the core, and the impregnation of the serving with oil, resin, wax, etc., or their compounds, yields the desired insulation resistance. In some cases the impregnation may be dispensed with, as the dry fibrous material offers in itself a certain insulation resistance which may be found quite sufficient for the case being. By this means, the object of having cheap and yet efficiently insulated cable conductors has been attained.

As all fibrous insulation is more or less hygroscopic, it is necessary to prevent any access of moisture; this is done by encasing such cores in a lead pipe, *i.e.*, forming them into so-called lead cables with impregnated or non-impregnated fibre or paper insulation, as almost every large cable-works manufacture them now with more or less success in one or another composition.

With the ever-increasing importance of telephonic communication and with the growing want of being able to speak at greater distances through cables, it became necessary to pay particular attention to the capacity of the cable-cores, as it was found that certain difficulties which were met with when trying to speak through a cable at great distance were caused by too high a capacity. The injurious influence of static capacity is already experienced on comparatively short telephone cable lines, inasmuch as the transmitted sounds are much more weakened than in passing through aerial lines; indeed, the result was such that at first it was given up as a hopeless case to use cables for long distances. Cable-makers were thus put to the task of inventing telephone cables in which the static capacity was to be reduced to a minimum, *i.e.*, in which the conducting wire is covered with an insulating material which, as regards static capacity, would yield the most favorable results. Atmospheric air gives, as is well known, the best result; next comes paper, then paraffine (twice the capacity of air), cotton, silk,

india-rubber, gutta-percha and glass (from six to ten times the capacity of air). A cable in which the conductors were surrounded by air would, therefore, give the best results as far as static capacity is concerned; but as the conductor cannot be kept central without a support of some sort or other, the best cable would be such in which the conductor was kept central in a pipe filled with air by the aid of the least voluminous supports, the latter composed of a material of the lowest possible static capacity, or in which the conductor itself was of such a form as to touch the insulating shell (pipe or tube) with the least possible portion of its surface. Of this latter alternative I have spoken before as a reason for using either twisted wire of a triangular, rectangular, or star-shaped section, or corrugated or zigzag wire.

The other alternative has been tried in various ways, viz.:

a. By filing beads of wood or ebonite or glass on the conducting wire.

b. By winding a line of thread or cord around the conductor in an open spiral so as to leave plenty of air-space between the windings.

c. By serving the conductor with an open braiding of cotton thread, or cord.

d. By interbraiding the several conductors with cotton thread, thus keeping them separate from one another by the thread and forming air-spaces between them.

e. By providing air-spaces in the insulating material (mostly paper tape) by curling or frilling or perforating or embossing the same.

f. By twisting a strip of non-conducting material about its own axis to form grooves or air channels in which the conductors lie.

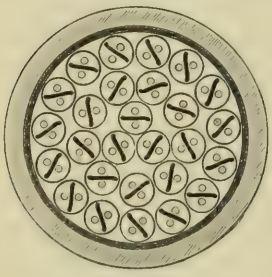


Fig. 230.

This last-named way of solving the problem is an invention of my firm (Felten & Guilleaume, of Mulheim-on-Rhine), whose patent lead cable, with paper insulation and air-spaces, has given the best results, the static capacity being reduced to 0.06 microfarad per statute mile at a temperature of 60° Fahr., whereas with other cables of the same proportions the capacity would be 0.48 microfarad with india-rubber, 0.16 microfarad with fibre insulation, and 0.08 (lowest) with the ordinary paper insulated

cables. Thus one can speak through a cable with paper and air insulation over a correspondingly longer distance with the same clearness of sound. This arrangement at the same time allows of the smallest diameter of the cable, and each core is easy to trace.

Another important factor in judging of the value of a telephone cable is the absence of induction, the presence of which is the cause of the most annoying cross-talk. The best and safest way of overcoming this difficulty will be the introduction of metallic circuits, *i.e.*, to do away with earth connection and provide two cores in the cable for each subscriber. However, this for one reason or another cannot be done in all cases, and where only single conductor cables can be used, provisions will have to be made to reduce the disturbing influence of induced currents to a minimum. This problem has been more or less perfectly solved in different ways, viz.:

a. It has been proposed to cross the cores at given intervals in the cable or in the cable joints, similar to what is done on aerial lines for the same purpose. This complicates the manufacture of the cables materially and attains the desired object but imperfectly.

b. Another way of making the cores cross one another at as near as possible a right angle has been proposed by twisting two cores together in very short windings.

c. The same leading thought has been instrumental in the invention of the solenoid (Lugo) cables, in which a portion of the cores are wrapped round the others.

d. The most effectual way of doing away with the annoying influence of induced currents is a wrapper of tin-foil around each core and the provision of one or more earth copper wires between the cores.

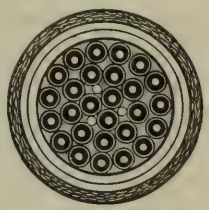


Fig. 231.

The wrappers of tin-foil collect the induced currents, and, as they are in metallic connection with one another and with the earth wires, the latter need only be connected to earth in order to remove the induced currents. It must not be overlooked, though, that the wrapper of tin-foil increases the static capacity.

Worth mentioning is the 28-core telephone cable adopted by the German postal authorities. This cable can be used as a single conductor-cable as well as for metallic circuit. To that end the 28 cores are arranged in 7 groups, each of 4 cores. The conducting wires are insulated with impregnated fibre, and each core has a serving of tin-foil. The 4 cores of a group are stranded around

a non-insulated copper earth-wire. These cables have given excellent results, and my firm (Messrs. Felten & Guilleaume, in Mulheim-on-Rhine) have recently constructed telephone cables on the same principle with their patent paper and air insulation, a thin copper strip being inserted in the cross-shaped paper-stay to collect the induced currents and lead them off to earth.

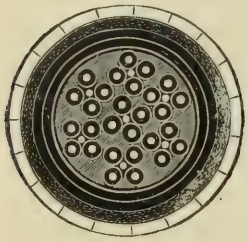


Fig. 232.

The safest way of preventing any annoyance by induced currents is, as said before, the application of metallic circuit; *i.e.*, to provide two lines in the cable for each subscriber. It has hitherto not been possible to more generally adopt metallic circuits on account of the cables becoming more voluminous and more expensive. With Felten & Guilleaume's patent paper air-space cable, however, this difficulty is to a great extent removed; their metallic circuit cables are very compact and neither much more voluminous nor much more expensive than the former single conductor cables, at the same time combining the lowest static capacity with an almost total absence of induction.

The splicing of these cables is very simple and can be accomplished by any jointer accustomed to jointing paper cables, the operation being almost the same.

Paper cables with air insulation are with equal advantage applicable to telegraphic service, only that all the dimensions of the conducting wire, cores, and cable will be comparatively enlarged. The diminution of static capacity not only prevents or, at any rate, lessens the transfer from one conductor to another—which so often is the cause of disturbances—but it also increases the speed of transmission or, at equal speed, the distance may be extended, thereby rendering the line more remunerative.

Cable manufacturers have been put to a perfectly novel task by the rapid development of electric lighting and electric transmission of power with the aid of currents of high tension. Here they had to deal with claims on the cable which were very different from those on telegraph and telephone cables. Static capacity, except with concentric and bi-concentric cables, is of less importance than the avoidance of danger arising from the insulation (in consequence of the heating of the conductor) being impaired or pierced by the high-tension currents.

Impregnated fibre and paper are largely used for electric-light

cables, especially since the introduction of alternate currents of more and more high tension. In this construction the insulating material must combine a great solidity with toughness and elasticity, qualities which no other materials possess in as high a degree.

The choice of the paper to be employed is a delicate matter. In consequence of the great variety of paper produced, it is necessary to exercise particular care when selecting paper for insulating purposes. The paper must have a low capacity and at the same time insulate well; it must also possess sufficient strength to stand the strain of the machines in covering the wires. A covering of paper in comparatively thin layers will do the needful; therefore paper insulation insures the smallest diameter of cable as well as a minimum weight and price.

THE PROTECTING ARMOR.

With gutta-percha and india-rubber cables the armor or sheathing is intended chiefly to protect the cable-core against mechanical injury. Submarine telegraph cables are sheathed with round galvanized iron wire. For deep-sea cables it is important that the size of the sheathing wires be reduced as much as possible while retaining a high tensile strength, and improvements in this direction have been made in the way of producing galvanized steel wire of very high breaking strain per square inch of sectional area.

Until the last year or two, No. 13 gauge wire, with a breaking strain of about 60 tons per square inch, has been employed for this purpose, but at the present time No. 14 gauge wire, with upward of 85 tons per square inch, is in use, and even No. 15 gauge wire finds employment.

The wires are served with a special compound as a better protection against the injurious effect of sea water. The ravages of the teredo and other insects on gutta-percha cables have been successfully done away with by lapping the core with brass strip.

With fibre and paper cables it is of utmost importance that the sheathing absolutely prevents the access of moisture. Therefore, these latter cables are invariably sheathed with lead, and the improvements which have been proposed in lead sheathing chiefly tend to having perfectly water-tight sheathing which will retain its water-tightness however badly the lead cable is handled.

As a protection against mechanical or chemical injury, a small percentage of tin is sometimes mixed with the lead, usually 3%;

also in some cases a second lead sheathing is put on with an intermediate layer of compound between the two sheathings.

Gutta-percha and india-rubber cables are sheathed with lead only when they are used as leading in wires and at stations.

Where the diameter and a smooth surface of the cable is of consideration, flat wires are used instead of round ones (as supplied by my firm to the German postal authorities), or the cables are sheathed with iron or steel strips. Underground lead cables for telegraphic and telephonic service are sometimes protected by a sheathing of galvanized iron wires over the lead; and where it is desired that the cable should have a smooth surface and the smallest possible diameter, my firm employs flat-shaped galvanized sheathing wire.

Fig. 233.

My firm have also introduced as a novelty the patent locked wire sheathing in connection with their submarine telephone cables with air-spaces. Such sheathing will keep off any strain or pressure from the core, which is so to say enclosed in a non-compressible tube.

Electric-light lead cables are often sheathed with galvanized wires and, in preference to other kinds of sheathing, with iron strip, which, if embedded in compound and with an external hemp serving, affords a most effectual protection.

Fig. 234.

Remarkable advances have been made in the way of laying submarine cables and in the appliances and machinery engaged therein, also in the construction of conduits for underground cables in towns; but I do not propose to enlarge upon such, as it would make me step out of the limits of this paper and as there are numerous publications thereon at the disposal of those who take an interest in these subjects.

A great deal more might also be said on so interesting a subject as cable-making, but what has been said will suffice to show what has so far been achieved and to mark the way for further improvements.

DXXXI.*

NOTE ON THE DRAINAGE MACHINERY OF THE NETHERLANDS.

BY A. HUET, DELFT, HOLLAND.

THE rise of the Dutch Republic in the sixteenth century was followed in the seventeenth century by a remarkable development in the art of draining the Lowlands, which had been so valiantly rescued from a foreign yoke.

Simon Stevin, the teacher of Maurice of Nassau, gave the theory of wind water-mills.

Leeghwater drained a series of deep lakes with scoop-wheels arranged in three tiers.

In the eighteenth century *Obdam* introduced the water-screw, and *Eckhardt* the inclined scoop-wheel.

In the first years of the nineteenth century *Peereboom* applied the horizontal centrifugal pump. Thirty years later *Lipkens* made his single-acting pump for the Haarlem Lake, and *Fynje* gave his double-acting pump.

In 1776, *Hoogendyk* made the first application of an atmospheric engine, and in 1786 he built the first single-acting steam engine, for drainage work.

In the first half of this century *Simons* pleaded successfully for the application of steam to the draining of the Haarlem Lake, which he and *Lipkens* realized in 1845 by the three pumping-engines, together of 1,000 H.P., with high-pressure steam, compound action, and condensation.

The history of the development of drainage machinery in the Netherlands has been given by the author of this notice in "Stoombemaling van polders en boezems" (The Hague, 1885).

A series of papers read by the author in the Royal Institution of Engineers has relation to the same subject; copies of these

* Presented at the Chicago meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

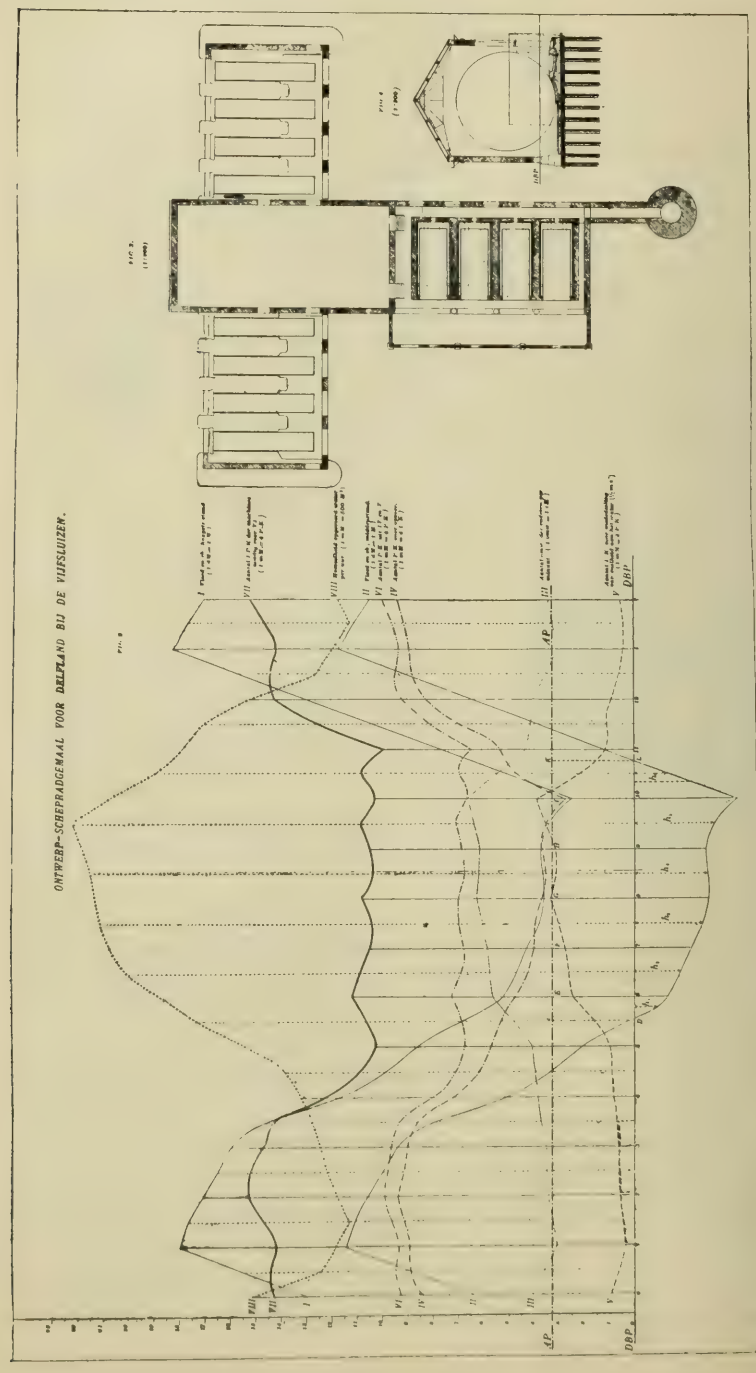


Fig. 235.

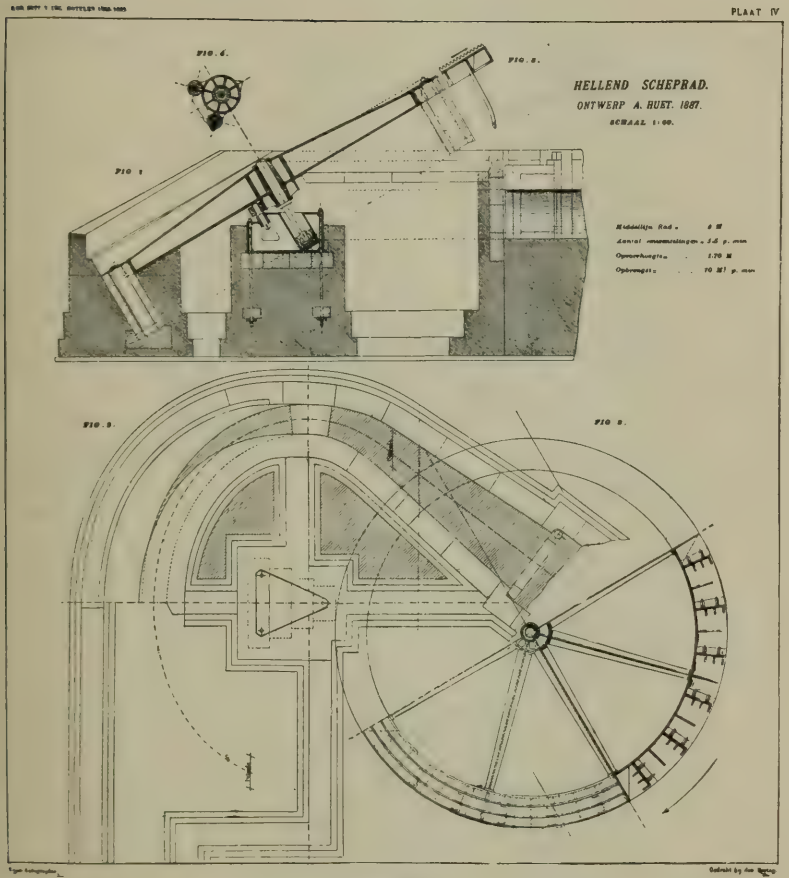

PLAAT IV
FIG. 4.
FIG. 5.
HELLEND SCHEPRAD.
ONTWERP A. HUET. 1887.
SCHAAL 1:100.
FIG 1
FIG. 3.
FIG 2.

FIG. 236.

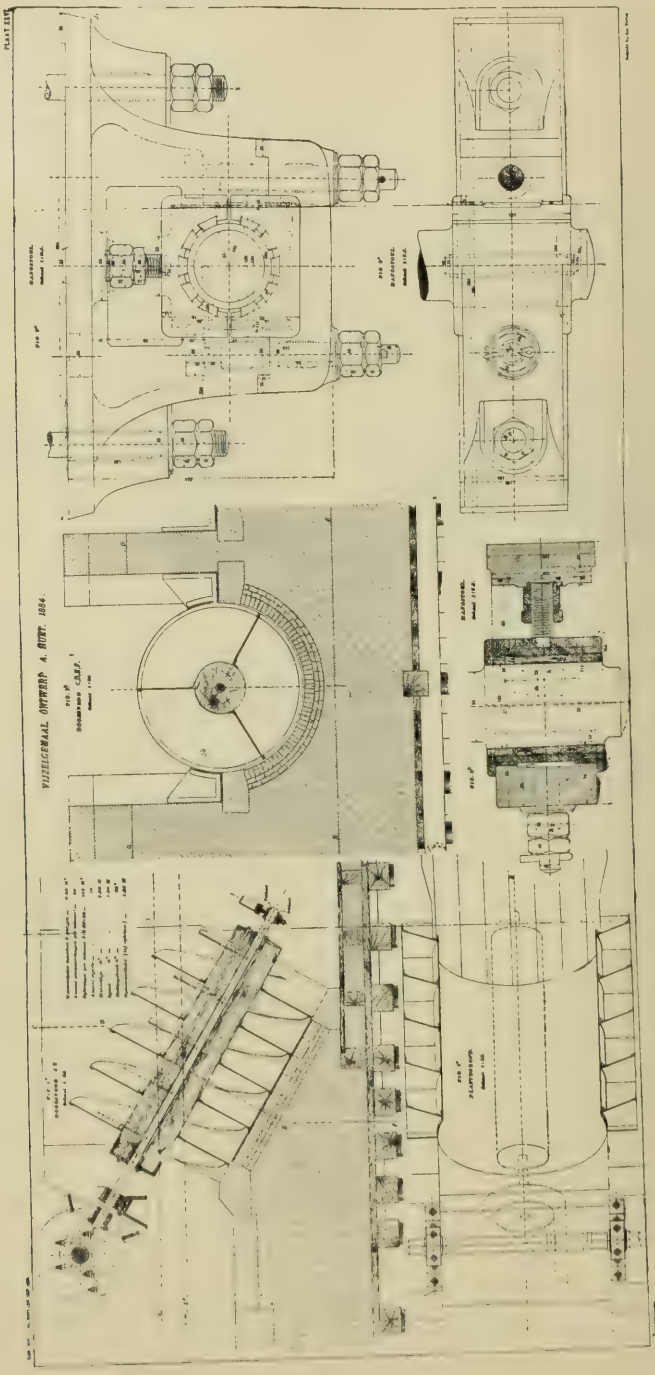


Fig. 237.

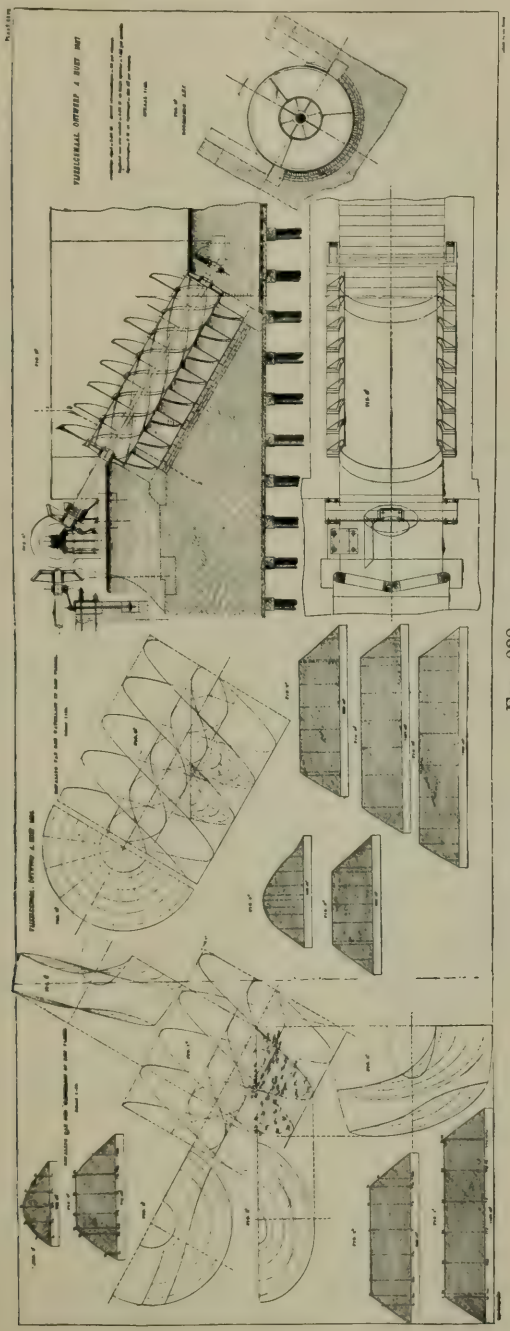


FIG. 238.

papers have been presented to the Library of the American Society of Mechanical Engineers and form a reference appendix to this communication, and will be briefly referred to.

No. 1, pages 4–6. List of drawings of draining machinery sent to the Paris Exhibition of 1889.

Fig. 235. Graphical treatment of the design for draining machinery with very variable height of lift.

Fig. 236. Simplified design for the inclined scoop-wheel in cast- and wrought-iron.

Figs. 237–238. Perfected design of the water-screw in wrought-iron, and a graphical calculation of the water discharge.

Figs. 239–241. Application of compound rotating steam engine to single-acting pumps.

Fig. 242. Architectural design for same. By G. T. Morre.

Figs. 243–246. Application of compound engines to double-acting pumps.

No. 8. Graphical calculation of the allowed height of suction with pumps of great piston velocity.

These papers are offered to the Division B of the Congress with the intention that at the expiration of the Congress they may be given to the American Society of Mechanical Engineers. Reproductions of their principal illustrations accompany this summary.

The leading thought in these papers is:

1. The application of modern machine design to those types of drainage machinery generally adopted in the Netherlands.

2. The reduction of the coal used in draining to the limit of 1.5 kilograms per useful horse-power in water lifted, which may be considered as possible.

3. The demonstration that by the use of single- and double-acting pumps a lower limit may be expected in the consumption of fuel.

The great interest of this question will be appreciated when it is known that for the drainage of the Zuiderzee at least 10,000 H.P. will be wanted.

The Haarlem Lake at present consumes fifty Dutch florins per horse-power yearly for coal and lubricants, because the consumption of fuel in the course of time has grown to 3 kilograms per useful horse-power in water lifted.

The reduction to 1.5 kilograms per horse-power would lead to a yearly expense of only 25 florins per horse-power, which would

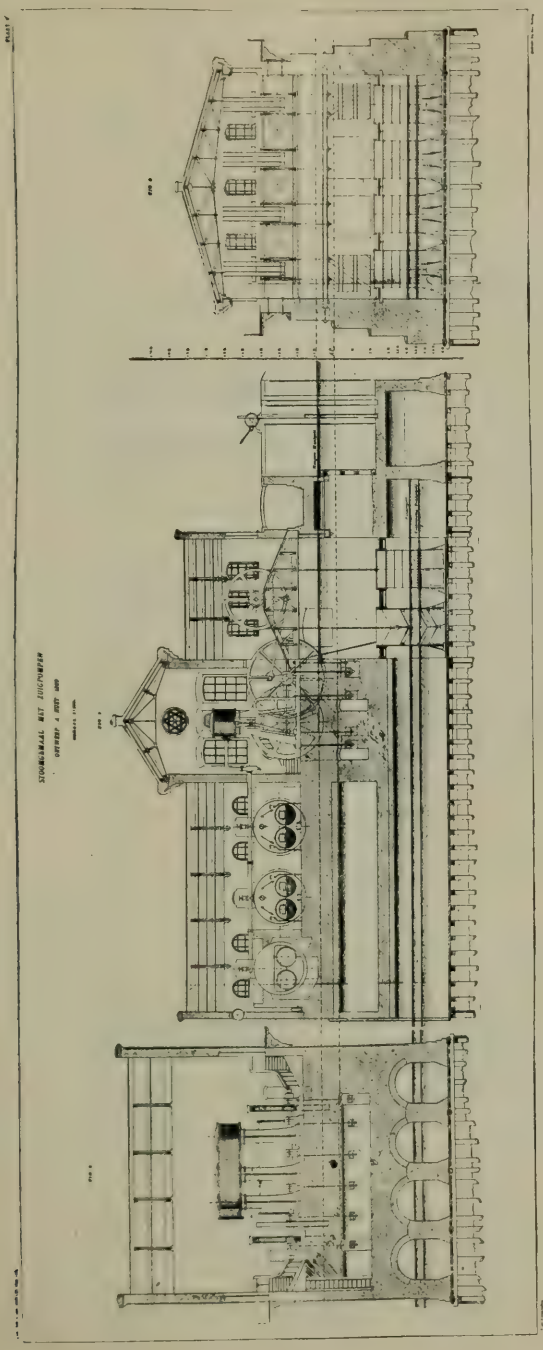


FIG. 239.

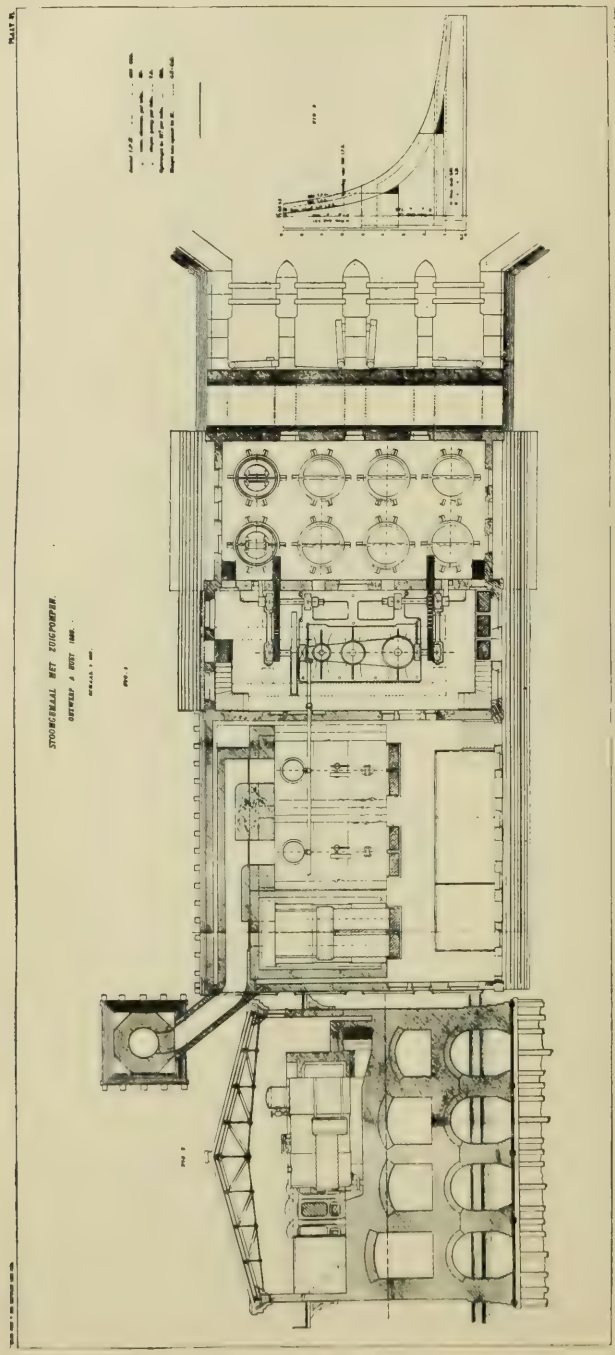


Fig. 240.

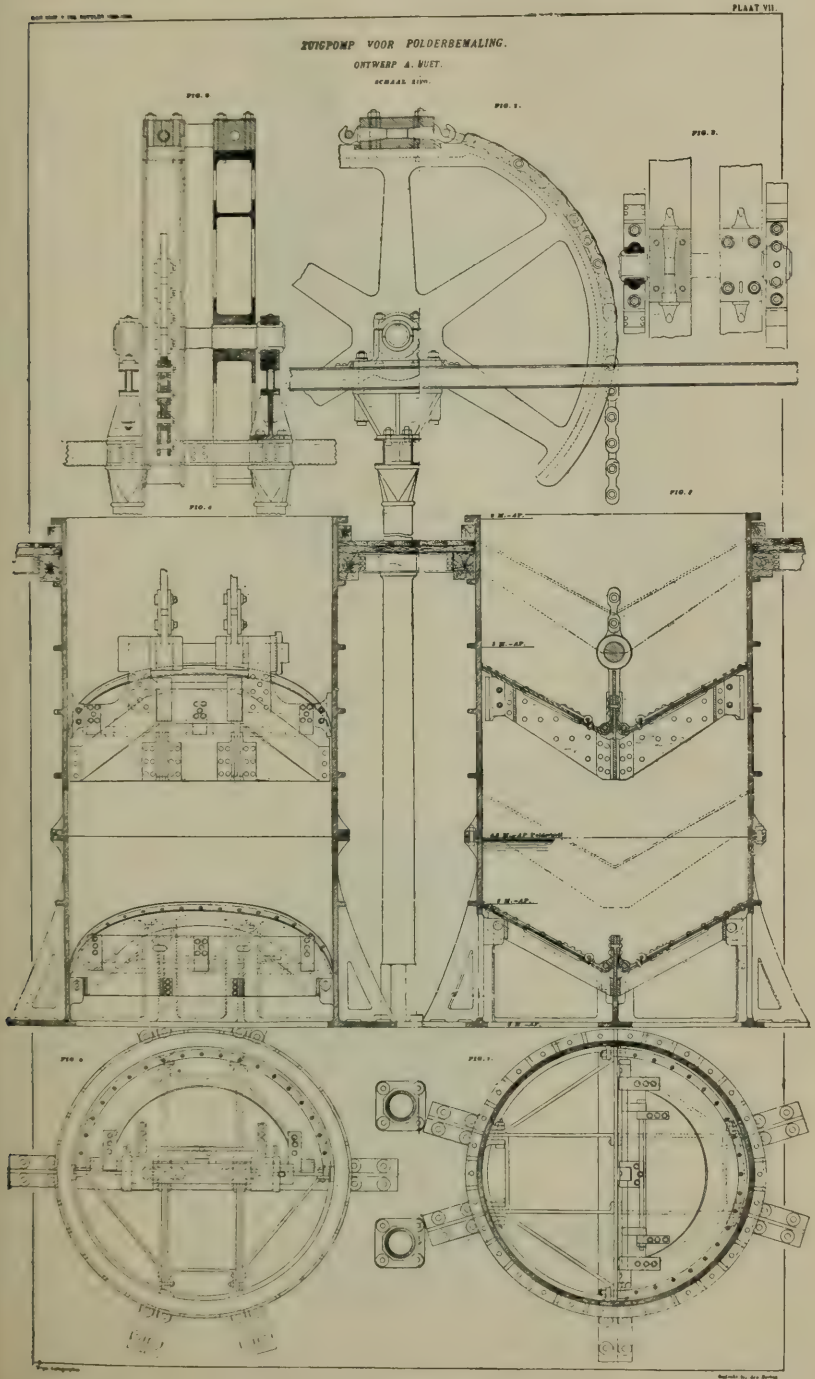

PLAAT VII.
ZUIGPOMP VOOR POLDERBEMALING.
ONTWERP A. HUET.
FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4
FIG. 5
FIG. 6
FIG. 7

FIG. 241.

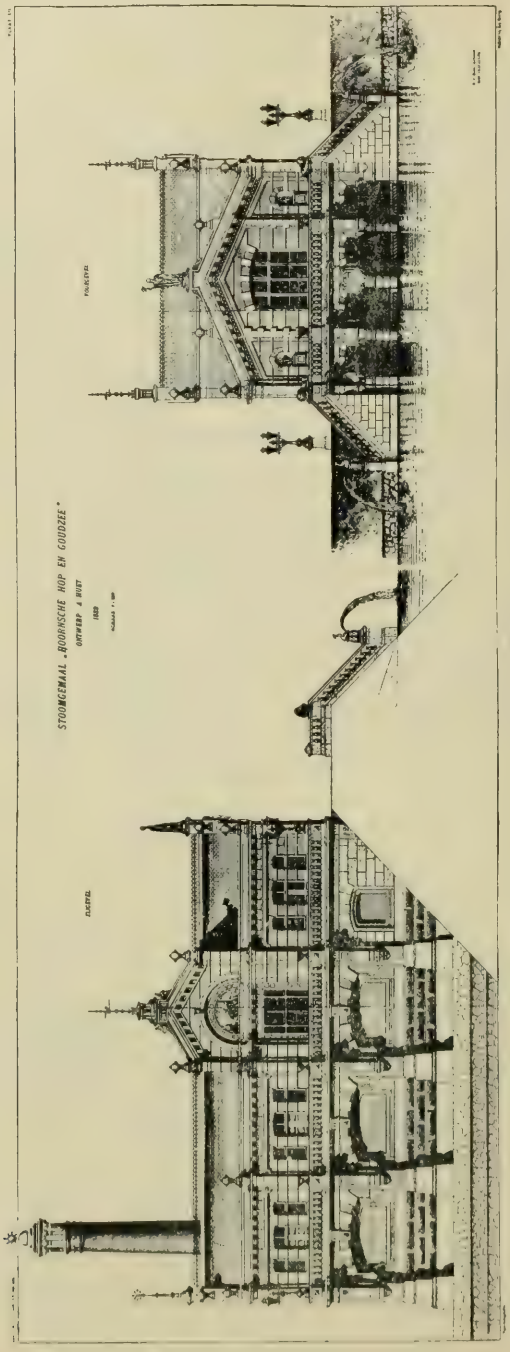


Fig. 242.

be equivalent to a saving of 250,000 florins yearly in the drainage of the Zuiderzee.

In the Dutch section of the Columbian Exhibition, among the display of the Royal Institution of Engineers, a series is given of three designs for drainage establishments in the Zuiderzee, each for a discharge of 360 cubic metres per minute, and a height of lift of 4.5 to 5.5 metres.

One of these designs has double-acting pumps, a second has centrifugal pumps, and a third single-acting pumps. An inspection of the drawings will show that with the centrifugal pumps the machinery is partly beneath the high-water level, which is always a disadvantage in case of flooding.

A copy of the historical work cited here above, "Stoombemaling van polders en boezems," will be found also in the Dutch section of the Exposition, in a case of drawings which are in use in the course of lectures on machine design which have been given by the author at the Polytechnic school at Delft since 1864.

The series of three designs named here above has been made by students according to the plans of the author of this notice. He regrets that he cannot be present at the Congress, but if he is allowed to propose a conclusion, it will run as follows:

CONCLUSION.

The consumption of fuel for well-designed draining stations should not exceed 1.5 kilograms of ordinary coal per useful horse-power in water lifted per hour.

This consumption may be reduced by the use of well-designed single-acting or double-acting pumps, driven by compound or triple-compound engines with tubular boilers and surface condensation.

The utmost limit which may be considered as attainable is 1 kilogram of good coal per useful horse-power per hour in water lifted.

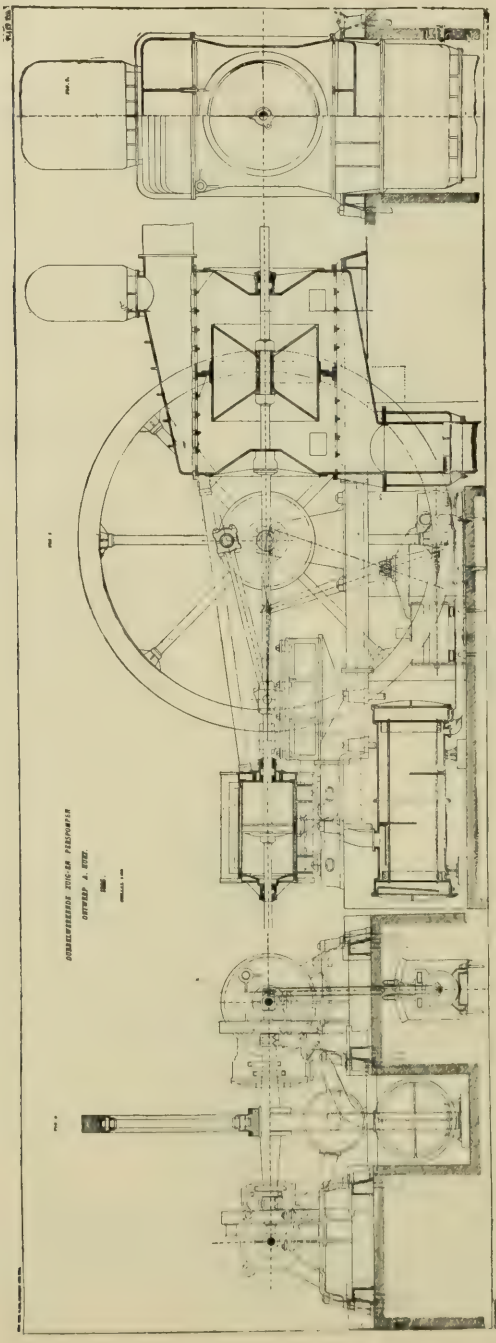


FIG. 243.

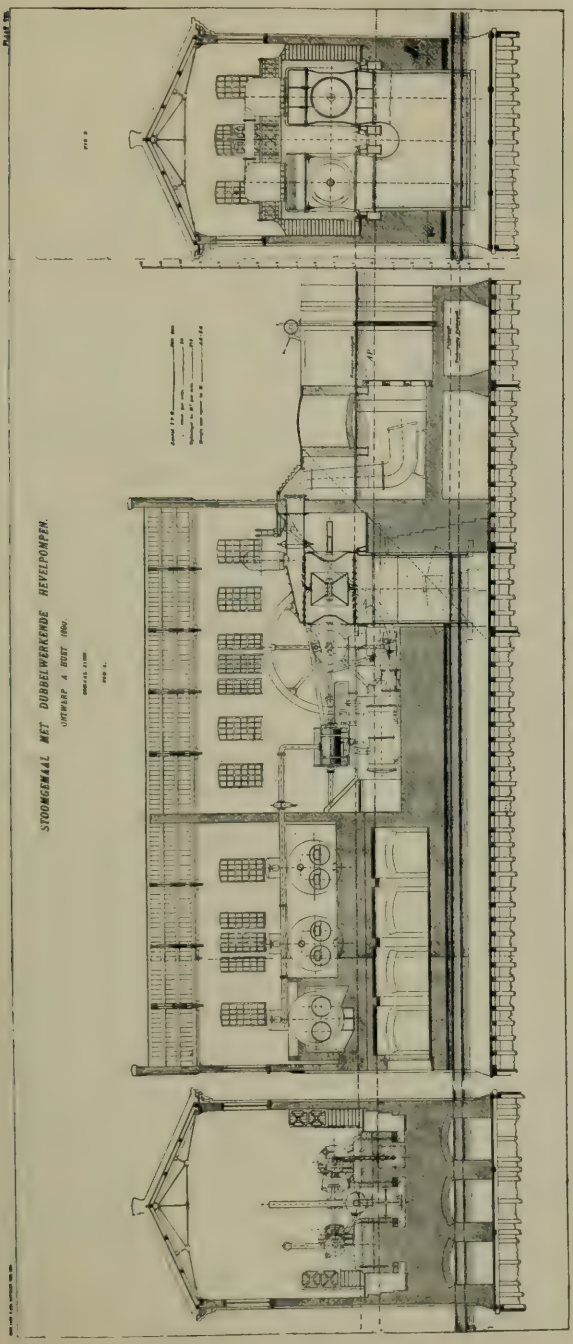

STOOMGEMAAL MET DUBBELWERKENDE REVELPOMPEN.
ONTWARP A. BOUT 1864.

FIG. 244.

DXXXII.*

LOCOMOTIVES OPERATING BY TOTAL ADHESION ON CURVES OF SMALL RADIUS.

BY A. MALLET, PARIS, FRANCE.

It is said that, when locomotives were first introduced, it took quite a time to convince engineers that the mere adhesion of the wheels of the engine on the rails was sufficient to effect the progressive motion of the former on the latter, and inventors wasted a considerable amount of intelligence in devising means to overcome the imaginary default of adhesion.

Although, for about a score of years, other means, such as racks and toothed wheels, have been adopted in mountainous regions, on railroads run for special purposes and of secondary importance, and notwithstanding some very interesting applications of the kind, we may correctly state that, from the beginning and up to this date, natural adhesion always and nearly exclusively remained the fundamental basis of the traction of locomotives on rails.

The first railroads were horizontal, and it has cost a great deal of money, since the problem became to overcome inclinations of even a few millimetres from the level. Under these conditions, the adhesion of only one pair of wheels proved sufficient to haul such loads as were customary in those times. It was seldom the case that recourse had to be taken to the coupling of two pairs. With the development of railroads, three or even four drivers have been coupled—and so far, no difficulties were met with on curves of the large radius, which alone were in use at that time. Little by little the railroads had to confront less easy alignments than they had had at their origin; people commenced already to conceive of the idea of going beyond mountains which stood in the way between country and country; steeper inclinations became imperative—it became a necessity to exact more effort of a locomotive, in order to convey remunerative cargoes over the new profiles: but thereby the

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

problem grew in complication, for reasons which we are going to discuss.

When there is a difference of level to be overcome and a maximum inclination to be taken into account, then the length of the line ought to be proportionate to this inclination; that is to say, the steeper the slope the shorter will be the line—the reduction in length being, as a general rule, the fundamental reason of the greater acclivities.

But as the natural slopes of the mountains are always far more abrupt than the steepest inclinations used on routes of communication, it becomes necessary to find the proper length in developing the alignment on the sides of the mountains, by describing loops, and, if the expediency so requires, to enter the slopes of secondary valleys in order to sufficiently lengthen the lines. Thus there must be introduced in the alignment numerous curves of a radius as far reduced as possible. To the aforesaid consideration there is, therefore, to be added the necessity of keeping near to the slope of the ground, in order to avoid elevations calling for important earthworks and passing round other natural obstacles, instead of undergoing the labor of tunnelling or surmounting them.

On general principles, it may be said that upon a railroad alignment steep acclivities are naturally allied with small-radius curves, and that these two difficulties together complicate the problem of the design of locomotives.

And, in fact, if the existence of steep inclinations require the use of engines of a considerable weight—that is to say, of engines having a great number of driving-wheels coupled together—on the other hand, the existence of curves of a small radius, exacting certain flexibility in the locomotive, render such coupling more difficult and sometimes even impossible.

Some isolated attempts have been made to construct machines above the ordinary calibre, as by Verpilleux, Tourasse, Eugene Flachat, and others, but they have not proved so successful as to answer the general expectations.

The competition opened in 1850, by the Ministry of Commerce and Public Constructions in Austria, for the best locomotive to be used in passing the Noric Alps by the Semmering Railway, signalized a date as remarkable in the history of railroads as that of Rainhill in 1829, from which the modern locomotive has resulted.

This Semmering competition, it is true, did not effect any direct and immediate results, none of the engines produced having been adopted, but, in spite of apparent failure, it furthered the study of the operation of locomotives on steep acclivities and afforded valuable notions so far as the difficulties of the problem were concerned; moreover, useful seeds were sown, which did not fail later to be conducive to important results, as will be seen further on.

The Semmering line, between Payerbach and Muerzzuschlag, exhibited for over 37½ kilometres a profile which comprised maximum acclivities of 25%, of which 3,175 metres are continuous; curves of a radius of 285 metres superposed upon these acclivities, and curves of a minimum radius of 190 metres.

Let us observe, by the bye, that such conditions seemed very easy in the face of certain actual alignments of secondary railroads.

Only such engines were to be admitted to a reward, which proved able to draw, in a regular way, trains of 140 tons over an acclivity of 25%, at a speed of 11½ kilometres per hour. The load should not exceed 14 tons per axle, and the pressure of the steam in the boiler 8½ kilogrammes per square centimetre.

There were presented four locomotives, and they were submitted to a test in the summer of 1857.

These locomotives were:

1. *Bavaria*, by Maffei, of Munich—a two-cylinder engine, driving seven axles, whereof two were placed under the tender. These seven axles were divided into three groups, and connected in each group by means of connecting rods, and the groups were connected by means of endless chains. A circumstance very little known is, that this locomotive was furnished with a variable expansion upon the system of Meyer, and to this peculiarity were ascribed the economical advantages afforded by this engine. The diameter of the boiler was of 1.60 metres, a then enormous calibre, which subsequently has very rarely been realized.

2. The *Wiener-Neustadt*, by Gunther, of Vienna—an engine with two two-cylinder trucks, with two axles, each placed under a single boiler having tubes of an extraordinary length: 6.38 metres. This engine carried its own supplies.

3. The *Seraing*, a Belgian engine, by John Cockerill, reported to be built on the plan of J. Laussmann, the chief of the

engine service of the Bergue-Marches Railroad. This locomotive had two two-axled trucks and two inside cylinders, each under a double boiler, or two boilers, connected by the fire-box. The supplies were carried on a separate two-axled tender.

4. *The Vindobona.*—This engine had been constructed in the shops of the Vienna-Glognitz Railroad. It had two cylinders acting on four coupled axles, the latter of which were at the back of the fire-box. It was in reality a three-coupled engine, to which had been added a fourth axle, owing to the excessive load on the wheels in its primitive arrangement. The boiler was of an oval transverse section, and this fact serves to explain the considerable number of tubes. The engine was followed by a tender on three axles.

Owing to the historical interest attached to these four locomotives, it is deemed appropriate to herewith reproduce the principal dimensions in the annexed Table A.

TABLE A.

Name of Machines.	Bavaria.	Seraing.	Wiener-Neustadt.	Vindobona.	Engerth System.
Grate surface	1.80	2.20	1.70	....	1.17
Total heating surface	168.	175.00	184.00	160.	155.00
Pression of boiler	7.	7.	7.8	8.	8.5
Number of tubes	250	340	180	288	189
Length of tubes	4.26	3.19	6.38	3.25	4.80
Number of cylinders	2	4	4	2	2
Diameter of cylinders	0.526	0.408	0.329	0.420	0.475
Stroke of the piston	0.762	0.711	0.632	0.578	0.620
Number of wheels	14	8	8	8	10
Diameter of wheels	1.100	1.042	1.106	0.948	1.110
Base of parallel axles	2.950	2.144	2.305	....	2.29
Base of extreme axles	11.00	8.237	8.120	4.500	6.06
Maximum weight in operation, in kilog	68,300	55,280	61,000	47,260	56,112
Load per axle, in kilogrammes	9,700	13,800	15,250	11,800	11,200
Traction effort, in kilogrammes	8,800	10,000	6,400	5,600	7,150
Adhesion co-efficient	1 to 7.8	1 to 5.5	1 to 9.5	1 to 8.5	1 to 8.

Besides those four machines, there were presented in said competition a great number of projects, by German, Belgian, and French constructors, comprising double engines, triangular connecting rods engines, toothed gearing engines, central-rail engines, etc., etc. None of these projects have been considered executable.

The four engines answered the absolute conditions of the contract: the first one, the Bavaria, very largely; and the last, the Vindobona, strictly. The Bavarian locomotive, which presented a very remarkable regularity as to speed, pressure, and consumption of fuel, besides a constant superiority as to power

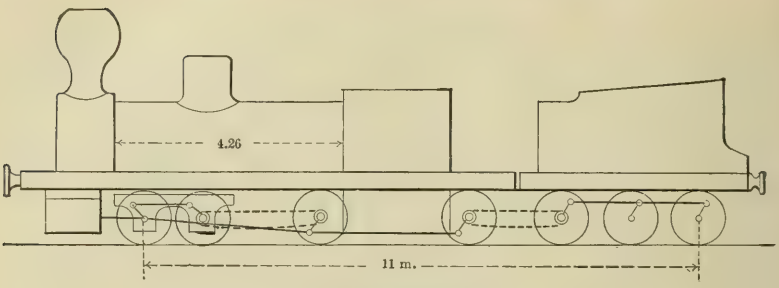


FIG. 247.—Bavaria.

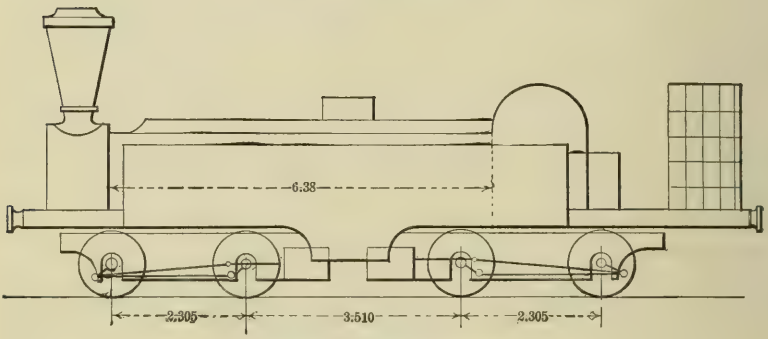


FIG. 248.—Wiener-Neustadt.

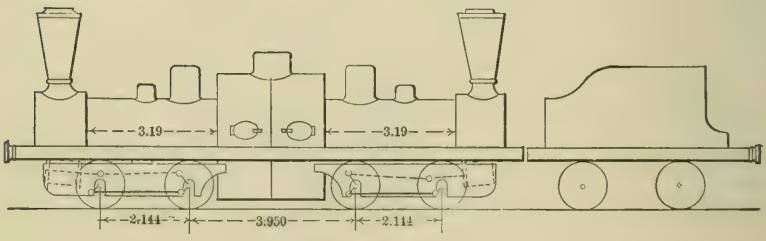


FIG. 249.—Seraing.

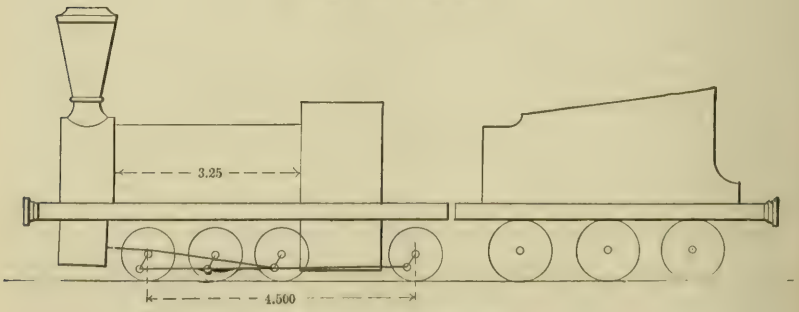


FIG. 250.—Vindobona.

and economy, was classed first by the jury; was therefore purchased by the government on the conditions established by the programme—that is to say, at a price of about 240,000 francs. Also the other ones, which had proved satisfactory at the trial, were purchased immediately or shortly after the competition, but having failed to perform a practical service, they were confined all under a shed of a station quite distant from the line, where one still could see them, some years afterward, abandoned to rust, awaiting the moment of their demolition.

It is but just to say that the Bavaria owed its victory to the very short duration of her trials only. It could not be preserved in working order except by employing the nights in repairing its transmission chains. A not less remarkable fact is that, precisely, of this preferred machine alone nothing has remained. The Seraing became the prototype of the Fairlie engine, the Wiener-Neustadt of the Meyer engine; the Vindobona, in fine, was the first eight-coupled engine—at least on the European railroads; but the Bavaria has nevermore been reproduced, neither near nor far.

The Engerth Locomotive.—It is a known fact that the Semmering Railway has been worked with combined engines by the eminent Austrian engineer Engerth, which have been denominated by his name. They were engines with five axles, three of which were under the engine and two under the tender; the wheels of each group were coupled by connecting rods, and the two groups were united together by toothed gear. The tender was linked to the engine by a spherical hinge and bore a part of the weight of the engine. The cylinders were two, and they were placed external, in the usual forward situation. This arrangement afforded the realization of *total* adhesion, by allowing the whole of the apparatus a sufficient flexibility.

But the gearing of the Engerth engine did not stand in service, and this system has been applied in an uncomplete form only, on a large scale in Europe, as an engine of partial adhesion; which fact, as ought to be admitted, justified but little her quite real though ephemeral success, especially due to the name of its designer and to the conditions amid which this system owes its origin.

The Engerth engine, in reality, proved to be only a tender engine with partial adhesion, of a very complicated arrangement. Nowadays the same results are obtained by placing at

the rear of a powerful tender engine a two-axle pivoting truck, which is a much simpler device. We present in the above table the principal dimensions of the Semmering Engerth engine.

An attempt was made, some years afterward, to revive the Engerth system in its complete form, by replacing the gearing with a jointed coupling-rod system. This system was applied about 1861 on the Austrian engine Steierdorf, and on two others. But it proved a complete miscarriage, all the talk made about it at the time notwithstanding; and, but for the fact that still on one or two Swiss railroads a few Engerth engines are in service to use them up, there would remain the remembrance only of a system which played a considerable rôle in the history of locomotives, although a very imperfectly justifiable one. The prob-

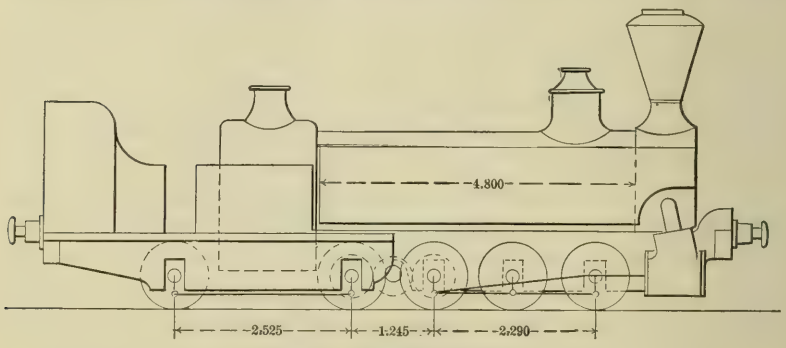


FIG. 251.—Engerth System.

lem of flexible adhesion engines has always since remained an open one, and the construction of economical railroads intervened now to arouse a new interest, and give birth to a great number of projects toward its solution.

As a general principle, it may be said that the various solutions which have been proposed for the construction of engines having a great number of coupled axles—four to six—and endowed with sufficient flexibility to run easily on small-radius curves, may all be included within the two following categories:

1. The systems by which the drivers operated by the ordinary two: cylinders are united together by means of arrangements fitted to allow their axles to adjust themselves to the curve, through parallel or radial displacement To this class belonged the Bavaria engine, and also the systems of Engerth, Steierdorf,

Polonceau, Dredge and Stein (central triangular connecting rod), Roy, Rarchaert, Larpent, Gouin, Beugniot, Klose, etc., may be added, to speak only of the best known ones. With the exception of the lateral play of the axles, which might be looked upon as a device for the imparting of flexibility to the machines, the only system of this category now employed is the Klose system, which we intend to dwell upon farther on.

2. The systems contemplating a division of the entire number of the axles of the engine into two independent groups, admit-

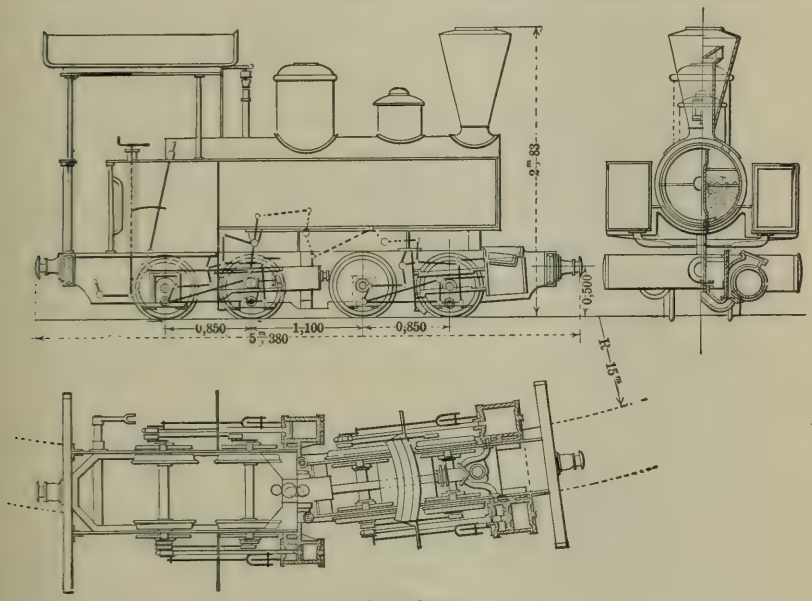


FIG. 252.

ting reciprocal displacement on the curves, and driven each by a pair of cylinders. To this class belong the Wiener-Neustadt engines and the Seraing, of the Semmering competition, as well as the systems of Verpilleux, Sturrock, Meyer, Fairlie, Johnstone, Thouvenot, Boutmy, etc. The two last mentioned remained only in the stage of projects, but the other enjoyed applications of more or less significance. As belonging to this same category might also be considered the independent engines which are put back to back, and employed on the *Giovi* and the *Victor Emanuel*, and also those more recently constructed by Neilson to be used in English India.

The engines of this second group may be said to have attained more of a comparative practical success, especially the Fairlie and the Meyer, although the unavoidable complication of their organs has been an obstacle against their development.

To this same category likewise belongs the engine which is the subject of this note, and which occasioned the following considerations:

In order to facilitate the passage of locomotives around curves the fore part of the engines are made to rest, especially in America, generally upon a pivoting truck with two axles.

Let us imagine a machine of this kind having at the back two coupled drivers controlled by a pair of cylinders, and at the fore part a two-axled truck—simply a *carrying* truck. (Fig. 252.) Such a machine will very easily pass round on curves, but only a part of its weight will avail for adhesion, and therefore on steep acclivities it will not be able to draw loads in relation to its total weight. If we allow the wheels of the truck to be worked by two cylinders of a convenient volume, placed upon this truck, and if we supply these cylinders by the exhaust steam of the back cylinders, we shall, by this very simple combination, have obtained three results:

1. We thereby allow the engine to utilize its full weight for adhesion.

2. We shall have suppressed the greatest difficulty of the articulated-pipe plan, as that of the Wiener-Neustadt, Seraing, Meyer, and Fairlie machines, in so far as the movable pipe-work of the new machine, in putting into communication the two groups of cylinders, will only allow issue to steam at reduced pressure—4 to $4\frac{1}{2}$ kilogrammes per square centimetre at the utmost.

3. Thereby we shall have realized a type of compound machine, affording advantages of different characters. This is the system which is both designated by the name of the author, and by the appellative of articulated compound machine, or *compound duplex*. Its more appropriate name should perhaps be: engine with articulated forward motor truck.

It is easily found that this system has, over the solutions that have thus far been presented, the advantage of a very great simplicity, as it has only one truck instead of two, and only one articulated pipe carrying slight pressure, instead of two pipes at high pressure. This system has been contrived by the author

since 1876, and presented in its present form in the year 1884. It has been for the first time realized in 1887, under the following circumstances :

It was under consideration to have engines made for the Decauville Railroad (of 0.60 metre track, rails of $9\frac{1}{2}$ kilogrammes per running metre), the weight whereof should be brought to nearly 12 tons and destined to pass around curves of 15 to 20 metre radius. The weight of the rail led to the use of four drivers, and the shortness of the radius of the curves was inconsistent with the coupling of four axles in the ordinary way. The project presented by the author seemed to answer the conditions of the programme, and a first engine was constructed on his plan ; it did its work in June, 1887. Its success was complete, and resulted in the construction of a great number of locomotives on this system for tracks of 0.60 metre, 0.75 metre, and 0.80 metre, types Nos. I., II., and III., shown in Figs. 253, 254, 255. The drawing herewith (Fig. 252) shows the general disposition in the plan, and in elevation as well as in longitudinal section. The frame of the engine, as may be seen, is divided in two parts, united by an articulation in form of a vertical hinge. The hinder part is fixed to the boiler, and the fore part of the latter rests on the fore frame by means of a curved groove which allows the angular displacement of the fore part in relation with the back part on curves. The cylinders of the hinder group are low-pressure ; the pipe-work that leads the steam from the boiler to them is fixed in the same manner as in ordinary locomotives ; the two groups of cylinders are united by a longitudinal tube acting as a receiver and bearing, near the hinge which keeps together the two frames, a vertical elbow which turns in a stuffing box : this articulation is the only one besides that of the exhaust pipe of the stack, and, as has already been said, it has to resist comparatively weak pressures only.

The rest of the engine does not present many other peculiarities. The transmissions of motion for the reversing gear, the brakes, etc., are effected by means of jointed rods of no serious complication nor opposing any difficulty to their installation. All these parts are far more simple than the corresponding ones of the Fairlie and the Meyer machines.

This paper is not intended to embrace a study of this engine, in their nature as compound engines. Nevertheless, the author is of opinion that he ought to point out that the adoption of the

compound system plays a capital rôle in this behalf, as it has mightily contributed to the simplification of the tube arrangement. Such an arrangement would be less understood in relation to the ordinary system; as in connection with the latter it would involve much more complication and would cause difficulties in its installation.

As we have said, there have already been constructed numerous engines of this system, for narrow-gauge roads, and especially engines for the Decauville tracks are to be found nearly all over the world.

The most noteworthy application was the Decauville Railroad at the Universal Exposition of Paris in 1889, where six such machines, at the rate of 16 hours' labor per day, have run 113,500 kilometres and conveyed over 6,000,000 passengers. This thorough test has brought forth the really practical character of this system.

Engines of this kind, and considerably stronger ones, have also been constructed for the railroad, with a 0.80 metre track, of the mines of Blanzy, type No. III. (Fig. 255). The author refers to this application in order to point out particularly other advantages following from the application of compound engine functions in the coal mines, where the saving of fuel is not a very important question. But an actual proof of the success of the adoption is given by the fact that not only did the company of the mines of Blanzy, twice in succession, order such engines for their use, but commended their adoption to other companies, especially to those of the Kebao coal mines in Tonkin, where they are likewise in operation.

The system has subsequently been applied to tracks of 1 metre, for which more types have been constructed, the most powerful among them being of the type shown in Fig. 256. It was made for the Landquart-Davos Railroad in Switzerland, and weighs over 40 tons at work. This line, which is situated in the Alpine regions of Canton Grisons, is, if we are not mistaken, that line which, through its locomotive and adhesion system, attains the highest altitudes in Europe; its culmination, the Wolfgang, is 1,633 metres above the level of the sea. It involves the overcoming of grades up to 45 per 1,000. In order to afford an idea of the profile of this railroad, it suffices to say that the difference of level between Wolfgang, which is the highest point, and Landquart, the starting-point on the

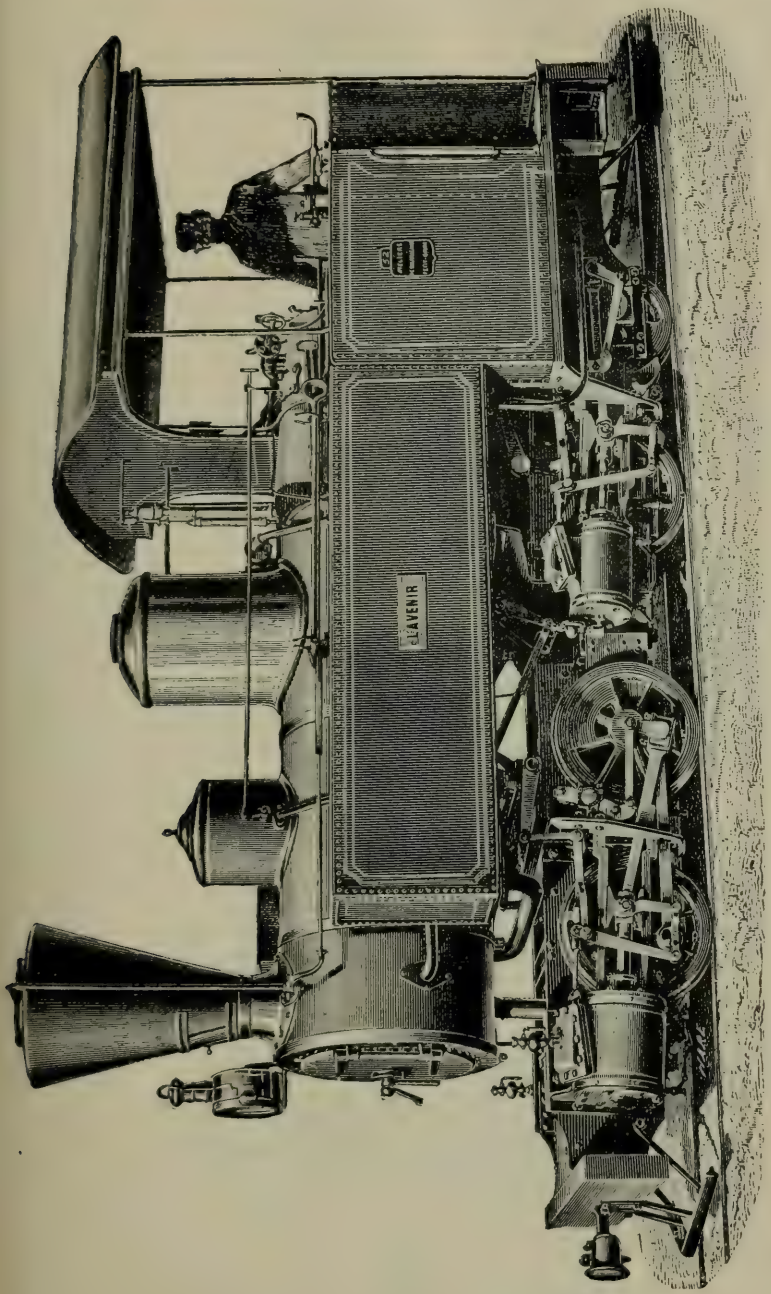


FIG. 253.

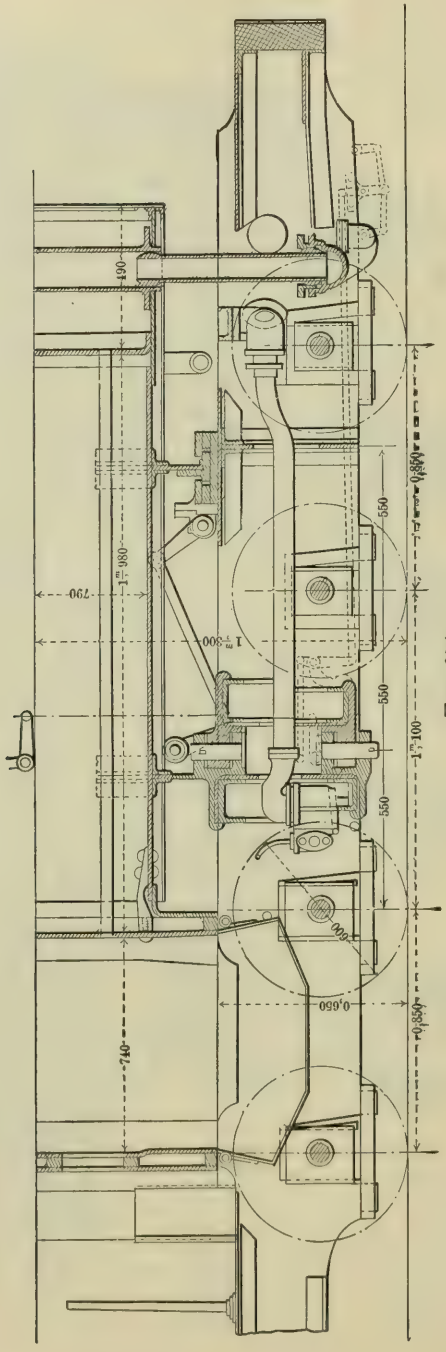


FIG. 254.

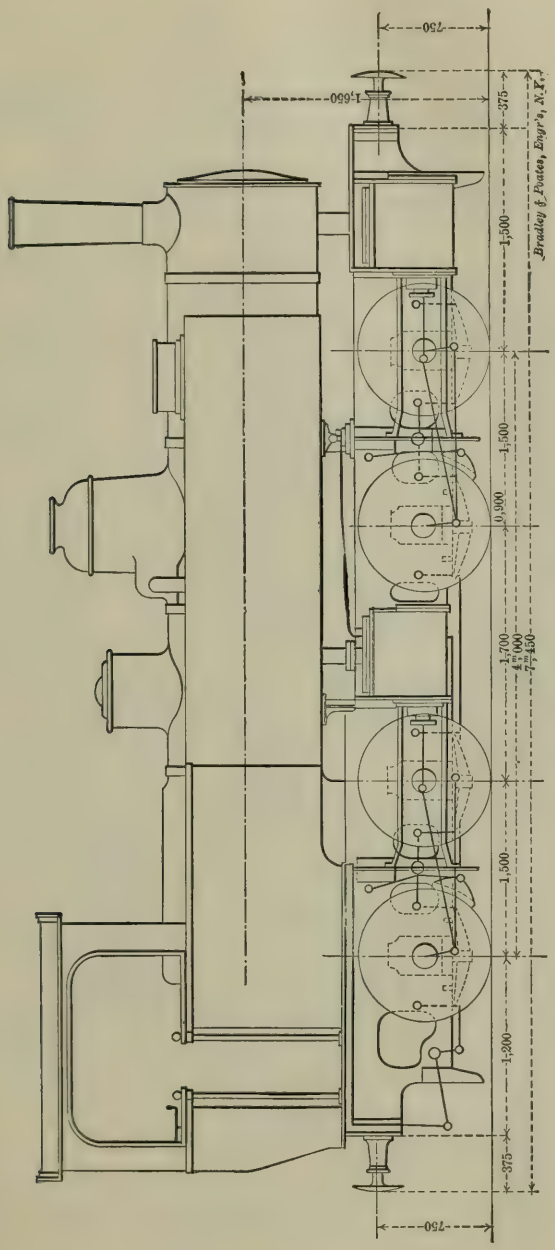


FIG. 255.—For 0.80 m. Track.

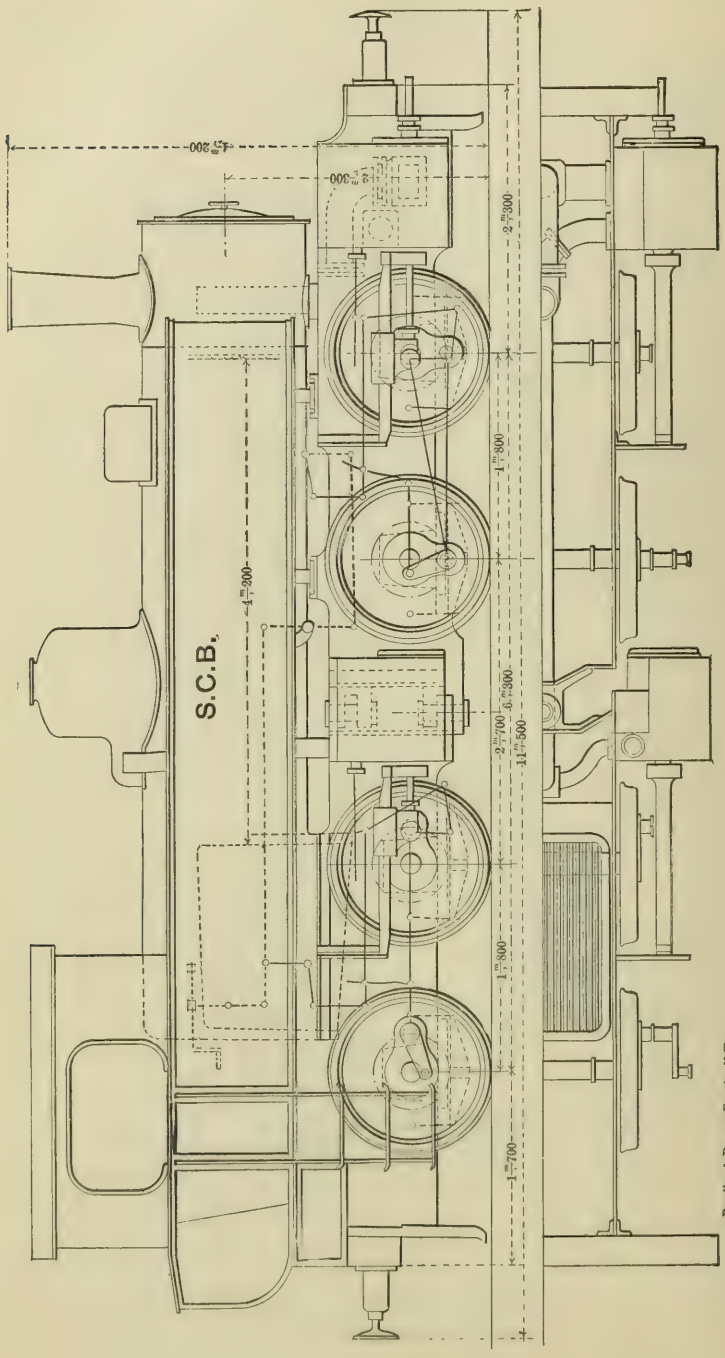


FIG. 256.—For 1 m. Track.

line Sargans to Coire (distant 43,524 metres one from the other), is of 1,106.7 metres, yielding an average declivity of 25.4 per 1,000. Between Wolfgang and Kublis, which latter station is 22,081 distant from the former, the difference of level is 820.6 metres—to wit, an average declivity of 37.1 per 1,000; in fine, between Laret and Klostersplatz, two neighboring stations distant 8,180 metres, the difference of level is 331.15 metres, exhibiting an average declivity of 40.4 per 1,000. The radius of the curves goes down to 100 metres.

The traction was first operated by Mogul engines having three coupled drivers and one carrying axle in front, weighing in operation 29 tons, whereof 24 were available for adhesion. These machines did not draw more than 45 tons on acclivities of 45 per 1,000. In 1890 there were added to them two articulated compound engines, of the weight above quoted, which draw 70 to 80 tons on the same profile. In ascending acclivities of 45 with a load of 70 tons at 18 kilometres per hour, these engines develop about 390 horse-power—an average of 5 horse per square metre of heating-surface. This latter is of 80 square metres, and this service must be kept up for a prolonged time. This type of engine, of 1 metre track, is more powerful than the average freight locomotive on normal routes. In a paper published in the December, 1892, issue of *Engineering*, Mr. C. S. de Riche Preller says that on the Landquart-Davos Railroad, which had been completely opened to traffic in 1890, two 40-tons Mallet locomotives, constructed by Maffei at Munich, perform the service for the freight and mixed trains, and that by the use of these machines the consumption of fuel has been reduced from 58 to 38 pounds per mile, or from 15.7 to 10.7 kilogrammes per kilometre, thus yielding a saving of 33%.

Also the 33-ton engine, on 1-metre track, of the Corsican railroads can be referred to as instances of the tractive power attained by locomotives of this system. They are of type No. V. (Fig. 257), and draw passenger trains of 52 tons at the speed of 33 to 35 kilometres per hour on continuous *gradients* of 30 per 1,000, combined with curves of a 100 to 150 metre radius—*gradients* frequently of a length of 5 to 5½ kilometres without stoppage. The corresponding power is 375 horse-power, which on 67 square metres of heating surface gives 5½ horse per square metre.

As it can very easily be inferred, this system has achieved a

real success on secondary railroads, as it affords an increase in the traction without increasing at that the load on the rails. A three-axle machine has an adhesion weight equal to 3, a four-axle machine an adhesion weight equal to 4; the power of the latter is therefore 33% greater.

If, moreover, the former has a carrying axle in front or at the back, as is generally the case now, then there will be little difference in the total weight of the two engines and the articulated machine besides its greater power will afford the advantage of lesser difficulties in passing over the curves. That is exactly what experience has proven in many instances. Let us take as an example the railroad of Montereau to Chateau Landon, which is a local railroad. The ordinary engines running on this road are engines with four axles, three of them coupled. They weigh 21.2 tons in operation, whereof 16.5 is adhesion weight, and draw at the utmost 70 tons over acclivities of 25 per 1,000, while the articulated compound machines of type No. IV. weigh 24.7 tons, whose entire weight available for adhesion, draws 100 tons on the same profile. Moreover, these engines realize a saving of from 15 to 22 per 100 of fuel in comparison with the others, and even more per every ton hauled, according to the importance of the load so hauled.

Less numerous are the applications hitherto made on normal routes, but their importance is considerable; and, to judge from the results obtained, the adoption of this system in a near future is decidedly to be anticipated on a large scale on first-class railroads.

In 1888–89 the Swiss Central Railroad ordered the construction of six four-axle articulated compound engines of type No. VIII. (Fig. 258), weighing 60 tons in working order. These locomotives issued from the works of Maffei, of Munich, who had constructed the Bavaria, of Semmering competition memory. The six engines were detailed to perform the service between Sissach and Olten, including steep gradients of up to 27 per 1,000, with a tunnel of 2,520 metres established on this declivity. The six engines yielded such excellent results as to induce the company to give another order for ten more engines of the same model, so that it actually owns sixteen. These engines are no longer restricted to the section of Hauenstein; they are now applied for the general service of freight trains all over the network of the line. The following abstract of a letter,

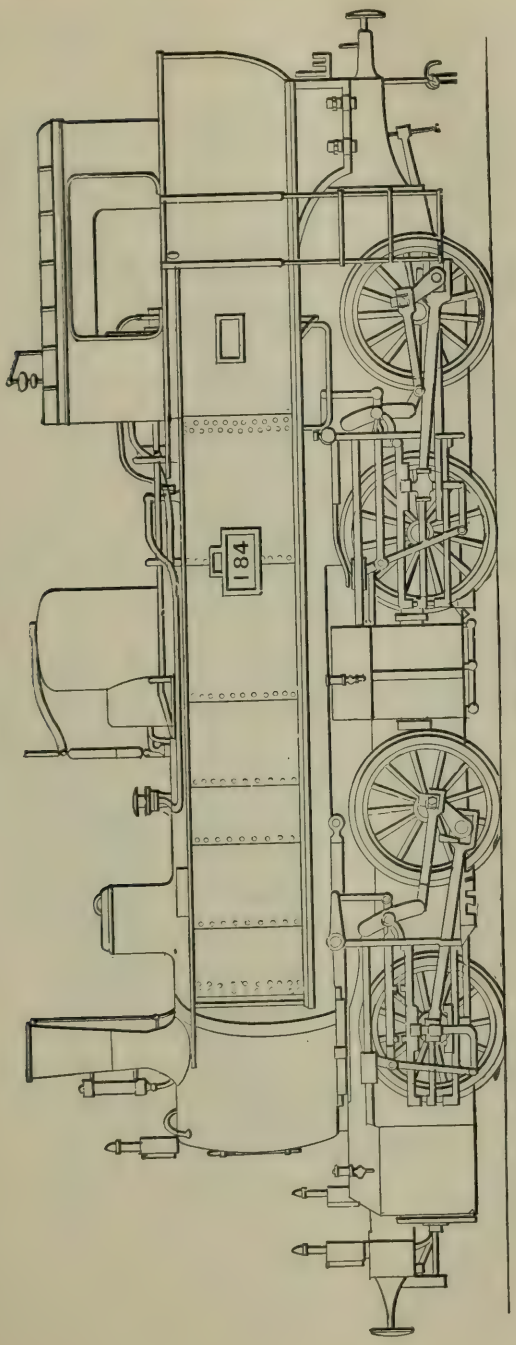


Fig. 257.

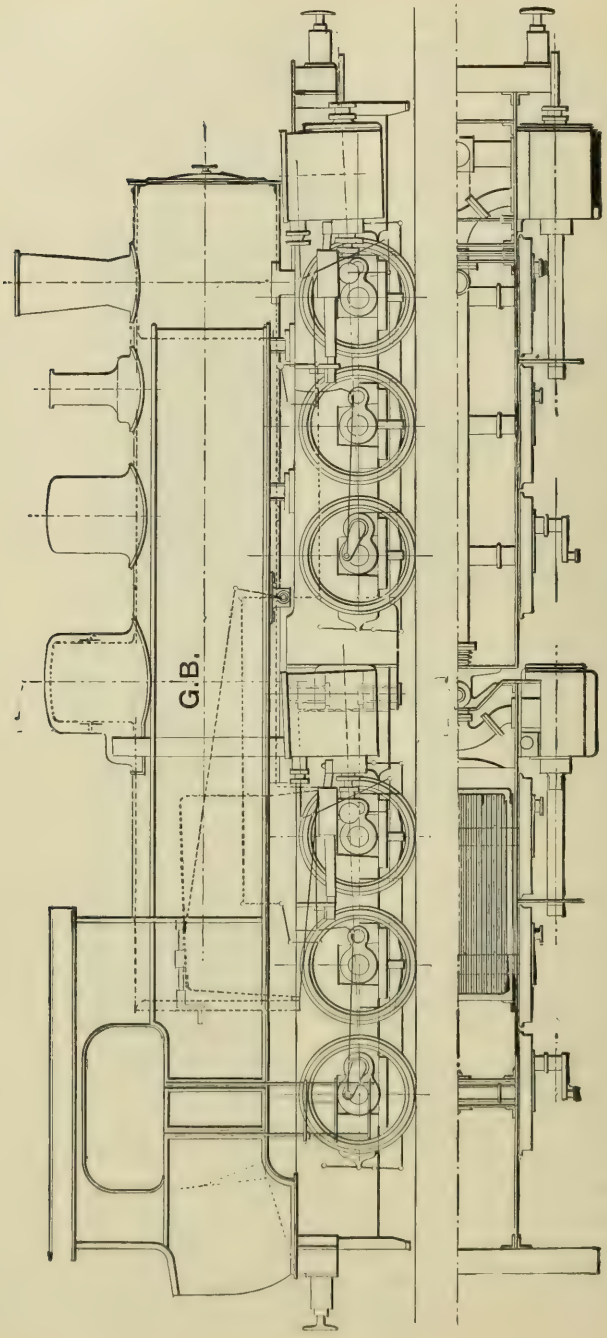


Fig. 258.—Swiss Central.

addressed in July, 1892, by the Traction Bureau to the contractors, testifies to the results obtained :

In response to your request, I am very happy to have to give you very favorable tidings with regard to the six duplex machines supplied by your firm. As you already know, a part of these machines do the difficult service of the Hauenstein tunnel, and a part are operated on the great line ; in this latter case they replaced the six-coupled-wheel freight engines, although they are able to draw far more. So far as the saving of fuel is concerned, we have found that, opposite to the three-coupled-axles, duplex engines yield a saving of from 15 to 22%, with equal labor. The wearing of the pieces of the mechanism of the duplex has been nearly naught during a service of over a year.

But the acme testimonial of satisfaction evidently exists in the second order of other ten machines like the former ones.

The same firm furnished in 1889, to the Gothard Railroad, an engine on the same system; to wit, a locomotive with six axles, divided in two groups of three axles each, which is the greatest locomotive in existence in Europe. It weighs 85,000 kilogrammes when fully supplied. The reasons which led to the construction of this type are to be found, not so much in the desire to possess a more powerful machine than the ordinary ones with eight-coupled wheels in operation on the Gothard, but to get additional safety, which is of most grave moment in the traffic of Alpine lines.

The ordinary engine weighs 54,000 kilogrammes, and has a separate tender of 30,000 kilogrammes when laden. In constructing the new machine the following aims were kept in view :

1. To haul the same trains by a same total motor weight and without increase of fatigue on the part of the rails, under more favorable conditions as to the adhesion, so as to have a guarantee against chances of distress in the tunnels, which are so numerous on this line, or from bad weather.
2. To haul heavier loads under good climatic conditions.
3. To obtain a far greater speed with like loads.
4. To offer less resistance on curves of 300 metres radius.
5. To effect a saving of fuel in hauling equal loads.

How important this last requirement is, will be easily understood when it is borne in mind that the engines consume over 30 kilos per kilometre of a fuel which costs 33 francs per ton, delivered on the spot

The new engine realized all the conditions of the programme, and in over two years of service not the least inconvenience

appeared to counterbalance the advantages which have been obtained.

So far as the first condition is concerned, one may easily reckon that, taking into consideration a train of 200 tons, the engine of the author draws 285 tons with an adhesion of 85 to 73 at minimum, or 4 for 1, while the ordinary machine is taxed 284 tons by an adherence of 54, or 5.2 for 1.

The advantage offered by the first engine from the point of view of adhesion is therefore 23%.

Some details as to this locomotive, which is of type No. X., and is represented by the drawing herewith (Fig. 259), may prove interesting. There are six drivers, divided into two groups. The rear group is in one piece with the boiler, and is operated by two high-pressure cylinders. The foremost group is controlled by two low-pressure cylinders, and linked to the former set by means of a working hinge placed about in the middle of the length of the engine. The boiler is 8.30 metres long, with a diameter of 1.47 metres, and contains 191 tubes 4.50 metres long, and is unchangeably secured to the rear frame, while it rests on the fore frame in grooves flooded with oil. The lateral displacement of the fore train is regulated by springs placed at each side in the fore part of the engine. The link-motion, on the Walschaert system, controls the trick-valves, and are united together by a single screw-gear. The axle-springs of the two groups nearest to the middle are on both sides coupled by an equalizing balance beam, and the two springs of the extreme axles are united by a transverse balancing beam.

The braking is done by means of four skids, or shoes, for each group, which are controlled by a vacuum cylinder; there are, therefore, two such cylinders, and, moreover, the skids of the rear group can be set by hand.

The water-tanks are disposed on the side of the boiler, and the coal storage is placed in the back of the engine. There are two sand-boxes, one for each of the axle-groups, with hand-movement in common for both. The machine is provided with an arrangement which permits the start to be by the direct and independent action of each pair of cylinders; it has been considered necessary to provide in advance for such use, in order to be prepared to eventually start heavily loaded trains on long acclivities of 26 to 27 per 100. The other engines of this system are generally furnished with an auxiliary cock only, allowing

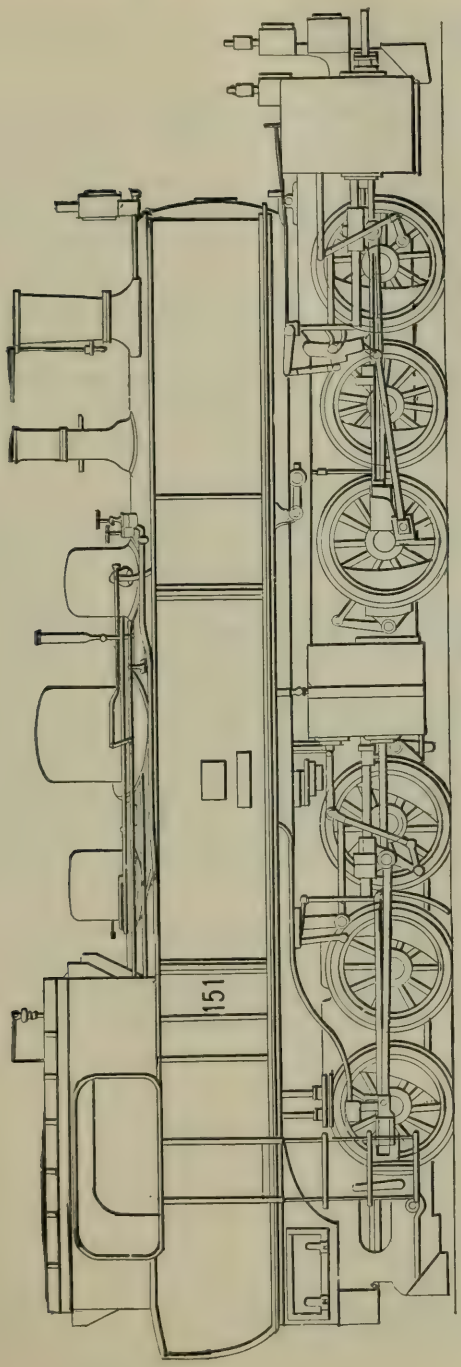


Fig. 259.—St. Gothard.

the direct transmission of steam from the boiler to the receiver, in order to facilitate the start. That is sufficient in the greatest majority of cases.

Before being sent to Switzerland the engine was subjected to trials on the line of the state of Bavaria, and between Munchen and Schliersee, over a profile comprising acclivities of 16 per 1,000, it hauled a train of 43 freight-cars, weighing 400 tons, at a speed of 20 kilometres per hour, which amounts to a traction of nearly 10,000 kilogrammes, and a duty of 750 H.P.; that is to say, 4.8 horse per square metre of heating surface. On the Gothard, in fair weather, it hauls 200 tons, while the ordinary engines do a work of 175 tons. It is known that the profile of mountain sections involves long acclivities of 25 to 26 per 1,000, and even of 27 on the southern slope between Giornico and Biasca.

Engines for the German Railroads.—In fine, in fall of 1892 the General Direction of the railroads of the state of Baden ordered two articulated four-axle compound engines, but with separate tender, to be used at the same time as the ordinary machines with four-coupled axles, for traction on the Schwarzwalder Railroad, which involves very steep grades and small-radius curves; the Royal Direction of Köhln (left bank of the Rhine) of the State Railroads of Prussia also ordered a similar machine for the ordinary freight service on the general railroad network. These machines, constructed in the shops of the Alsatian Society at Grafenstaden, will be operated during the summer of 1893. They are shown in No. IX., Table B, of general dimensions.

Above, we said that the only system belonging to the first category—that is to say, where two cylinders only control an ensemble of axles affording a radial displacement of the same in the curves in use nowadays—is the Klose system.

TABLE B.

	Tracks below 1 Metre.			Tracks of 1 Metre.			Normal Tracks.			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
	Decauville.	Quiros.	Blanzy.	Departmental.	Corsican.	Landquart-Davos.	Herault.	Central Swiss.	Germany.	Gothard.
Grate surface	0.48	0.68	0.93	0.78	1.05	1.44	1.50	1.70	1.94	2.20
Total heating surface	22.30	29.00	39.00	42.00	67.90	80.20	76.50	106.00	145.00	155.00
Pressure in the boiler, in kilogrammes	12.	12.	12.	12.	12.	12.	12.	14.	12.	12.
Diameter of high-pressure cylinders	0.187	0.210	0.230	0.250	0.280	0.350	0.305	0.355	0.390	0.400
Diameter of low-pressure cylinders	0.280	0.320	0.350	0.380	0.425	0.430	0.400	0.540	0.600	0.580
Stroke of pistons	0.260	0.320	0.350	0.460	0.500	0.550	0.520	0.610	0.600	0.640
Diameter of wheels	0.600	0.720	0.800	0.900	1.000	1.050	1.200	1.200	1.260	1.230
Base of axles of each group	0.850	1.000	1.100	1.150	1.400	1.600	1.450	1.680	1.750	2.700
Base of extreme axles	2.800	3.400	3.750	4.000	4.670	5.200	5.000	5.580	5.800	8.130
Capacity of water-tanks	1,400	1,800	1,900	3,000	3,700	3,500	3,700	7,500	.....	7,000
Weight of empty machine, in kilogrammes	9,300	12,500	15,500	19,000	26,000	32,500	28,000	44,500	48,500	67,000
Weight of machine in working order, in kilogrammes	11,700	16,000	18,500	24,500	33,000	40,500	36,000	60,000	54,500	85,000
Effort of traction, in kilogrammes	1,800	2,400	2,700	3,800	4,800	6,000	5,000	8,500	8,700	10,000
Weight of rail, in kilogrammes	9.5	12	15	18	22	23.5	25	37	.....	37 to 48
Minimum radius of curves	15	20	25	40	50	70	55	90	95	120

Remark.—Type IX. is with separate tender ; type X., with six axles.

Mr. Klose, formerly an engineer of the railroads of the Swiss Union, the present manager of the Material Department of the Würtemberg Railroads, some years ago contrived a very ingenious coupling system, whereof the drawing herewith affords a summary notion. (Fig. 260.) The pin of the crank of the motor driver bears a sort of lozenge whose two tops carry the connecting rods of the other axles; the inclination of the lozenges will allow, in one sense or the other, the approaching or the separation of the wheels, and when they approach on one side, and separate on the other, the radial displacement will occur, without discontinuing the coupling of the axles. The two other tops of the lozenges are connected by means of links and connecting rods to the drivers, not thoroughly indicated in the drawing, and very complicated, so that the convergence of the

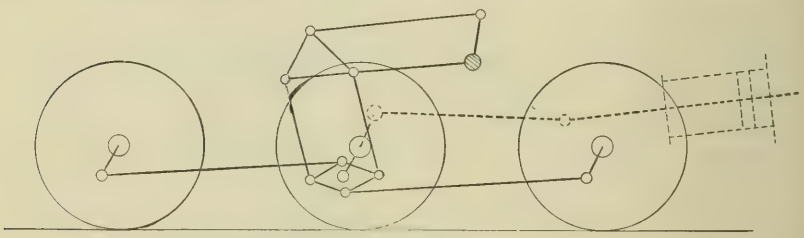


Fig. 260.—Klose System.

axles is in relation with the variation of length of the connecting rods.

This system has been applied to engines on tracks of 0.76 metre on the Bosnian Railroads, and on large engines with four drivers of the Würtemberg Railroads. These latter are compound engines with three cylinders.

Comparison between the Klose System and the Author's System.—An article of the *Zeitschrift des Vereines Deutscher Ingenieure* (Journal of the Union of German Engineers), in its issue December 24, 1892, presented a comparison by Mr. Helmholz between the Mallet machine and the Klose machine, where he describes, as follows, the respective advantages of the two systems:

The Mallet System.—1. Less resistance of the engine, owing to lesser number of axles coupled together.

2. Better utilization of steam, by the use of the compound system, whence the possibility, at an equal heating surface, of realizing the same work at a greater speed.

3. Less complication, the pieces being simply duplicated.

Systeme Klose.—1. Greater stability for a same minimum radius of curves, whence a possibility of greater speed.

2. Better utilization of the adhesion, because with the Mallet machine one ought to regulate the effort according to the load of each group. The latter one affords only an adherence of $\frac{1}{4}$, while the machine Klose goes down to $\frac{1}{6}$, even to $\frac{1}{5}$, whence a greater effort of traction by equal weight.

3. Suppression of all articulated-pipe arrangement.

The author is of opinion that the inferiority attributed to his system by Mr. Helmholz, so far as these three points are concerned, does not practically exist.

1. This sort of engine is not destined to run fast. Nevertheless, with the use of some regulation springs conveniently disposed on the fore truck, a speed of from 50 to 60 kilometres per hour may be obtained without inconvenience, with wheels of 1.20 metres of diameter. Experience has repeatedly proven it. And machines which, after all, are equivalent to those of eight-coupled wheels, cannot be taxed more than that.

2. The adhesion can be made use of just in the same limits as in ordinary engines, provided that in each group the effort be proportioned to the load borne by the wheels and that only for the maximum degree of effort. In general, both groups are equally laden, so that it suffices to cause the pistons' strain to be equal on all the groups. Nothing is easier done, as it ought only to be done so far as the maximum effort is concerned, the only one which is of interest. In fact, there are daily realized efforts corresponding to adhesion far stronger than $\frac{1}{4}$. At the already mentioned railroad of Montereau-Chateau Landon, engines of 24 tons have often drawn 108 tons on acclivities of 25 per 1,000 with curves of 100 metres. The effort, therefore, is very near to 4,000 kilogrammes, and corresponds to the sixth part of the weight of a 24-ton machine. It would prove a very easy thing to multiply these instances.

3. When the articulated-pipe arrangement consists of only one piece, allowing the passage to steam at 4 or $4\frac{1}{2}$ kilogrammes of pressure, no importance should be attached to this question, especially in the face of a formidable array of links and levers of the Klose machine. There are engineers who are afraid to employ an articulated joint, and in order to avoid an imaginary difficulty (absolutely in keeping with the other imaginary

insufficiency of the adhesion at the time when railroads originated), they just entangle themselves in most excessive complications.

Comparison with the Johnstone Machine.—The author believes that this is exactly the case with the Johnstone machine of the Central Mexican Railroad, while, on the other hand, he does not disown its surprising ingenuity. In comparing this machine to the above-described Gothard machine, we find that it has more than the latter: one boiler, four wheels, four cylinders, eight piston-rods, four motor rods, and a number of transverse beams, links, etc.; all this mostly in order to avoid a single movable joint at low pressure, which have been in use on over one hundred engines, and in six years of work so far, even the very earliest ones never gave rise to the least difficulty.

CONCLUSION.

Summing up—it ought to be considered an already established fact, that the construction of a locomotive with total adhesion and sufficient flexibility, of a true practical character, is a question of real interest and very important, since for so many years people have tried and still are trying to find its solution.

The interest of this problem lies in the following points, which can be stated in a very plain and complete manner as follows:

1. To provide existing lines with engines of greater tractive power and operated more economically than the present engines, without increase of fatigue on rails or of resistance to passing around curves.

2. To enable the construction of new lines, having, with equal capacity, lesser radii and rails lighter than those required by the present engines.

Nobody will deny that the solution of this double problem will exercise a beneficent influence with regard to the expenses of the construction and of the traffic of railroads, when they must be laid with varied profiles, as nearly constantly superinduced by the configuration of regions where new lines are to be constructed.

The author, in fine, believes that the system which gave its subject to this paper does fulfil the conditions which may be exacted of a machine of this kind. He could give no better

proof of the efficiency and practical character of his system than the fact that he, a civil engineer, attached to no railroad companies at all, neither nigh nor afar, nor to any engine-shop, nevertheless succeeded in placing in four years 110 machines of this system with over twenty different administrations, some of them of the very first class. And whosoever knows how difficult it is to have adopted something new in the industry of railroads, under such conditions as have been described, will consider this proof a peremptory one.

The following is a list of Railroad Lines on which these machines are employed:

TRACK BELOW ONE METRE.

1. Machines furnished by the Decauville Co., for sugar mills, exploitation of forests, mines, etc.
2. Carrière des Marechaux Railroad (Ville de Paris).
3. 1889 *Universal Exposition* R.R. (Decauville).
4. Royan Tramway (Decauville).
5. Calvados Tramway (*idem*).
6. Toury-Pithiviers Tramway (*idem*).
7. Phu-Lang-Thuong to Langson R.R. (Tonkin).
8. Blanzy Mining Comp. (J. Chagot et Cie).
9. Laurium Mining Comp. (Greece).
10. Trubia-Quiros R.R. (Spain).
11. Kosta-Lessebo R.R. (Sweden).
12. Railroad in Roumania (track 0.75.)

TRACK OF ONE METRE.

13. Montereau-Chateau Landon R.R. (Departmental).
14. La Voute-Yssingeaux R.R. (Departmental).
15. Tournon-Lamastre (Departmental).
16. Corsican R.R. (Departmental).
17. Allier R.R. (Economical).
18. South France R.R.
19. Durango-Zumarraga (Spain).
20. Madrid to Villa del Prado (Spain).
21. Landquart to Davos (Switzerland).
22. Saignelegier to Chaux de Fonds (Switzerland).
23. Yverdon to Sainte Croix (Switzerland).
24. French Society of Kebao Coal Mines (Tonkin).

NORMAL TRACKS.

25. Railroad of local interest in Herault.
26. Central Swiss R.R.
27. Gothard R.R.
28. Railroads of the State of Baden.
29. Prussian State R.R.—Direction Cologne (Köln), left bank of the Rhine.

DXXXIII.*

ON WATER MEASUREMENTS, WITH SPECIAL REFERENCE TO SCHINZEL'S EBONITE WATER-METER.

BY FRIEDRICH LUX, LUDWIGSHAFEN, GERMANY.

An eminent authority has recently expressed an opinion that the time was not far distant when, in all municipal water supplies, the water-meter would find universal acceptance. It is really a matter of astonishment that although nobody in our days would dream of measuring gas without gas-meters—*i.e.*, by mere rough estimate—this actually continues to be done in the case of water, just as, only a few years back, it was the custom in electric lighting.

As a brilliant exception we may mention Italy, where not only the single houses but even the individual families possess water-meters.

The reason generally given for this striking fact, that in Germany water-meters as yet are not in general use, is the pretended untrustworthiness of these instruments for purposes of measurement.

Considering that the first patent for water-meters was taken out as early as 1824, and that, at the present time, more than five hundred constructions already have been patented and published, it certainly appears very astonishing that this apparatus should not have attained that degree of perfection which might be expected from an instrument of such importance.

The first piston water-meter was patented in 1828, by Brunton, and the first wheel meter in 1858 by Dunn. In 1825 Siemens published his water-meter construction. It would lead us too far to give even a cursory view of these different systems; I will content myself with a bare enumeration of the categories into which they could be divided.

There was first of all, as the primary idea, the principle of tilting vessels, two vessels fitted to an oscillating lever with equal arms, which alternately fill and empty while the oscillations are registered by clock-work.

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* Presented at the Chicago meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

This system was not easily applicable for high-pressure systems. An attempt was made to introduce compressed air in order to keep the upper portion, in which the tilting vessel moves, free of water; but it met with no success.

This system, however, even in our days, is successfully used in the measurement of valuable fluids, such as, for instance, the alcohol measurements of the excise officials in the spirit distilleries of Austria.

Another system is based upon the application of the wet gas-meter in this wise, that, whilst in the gas-meter the lower portion contains water and the upper gas, mercury was now employed as the confining liquid over which the water, as the liquid to be measured, was freely allowed to flow.

Also the dry gas-meter was tried for the measurement of water. This experiment again failed, for the simple reason that, in a main, the jerks are frequently so violent that the delicate membranes of a dry gas-meter cannot, for any length of time, bear up against them. Then follow the two categories which have found a more general application. These are first the "space or piston water-meter," with piston either reciprocating or turning or rotating; then the "speed or winged-wheel water-meter," either, as in the majority of cases, as a direct-action wheel—that is to say, as a wheel with wings directly actuated by the in-flowing water itself—or as a reaction wheel, such as first constructed by Siemens, and as still in use in England.

Another system, that of differential or instantaneous water-meters, which is now well adapted for the registration of the quantities of water passing, has been successfully applied in the so-called district water-meters (Frankfort-on-the-Main).

As curiosities may be mentioned two constructions which try rather to circumvent the problem than to solve it. One proposal was to join a closed water-cistern to a gas-meter and to determine indirectly, by measurement of the air received, the quantity of water taken out. The second proposal was to insert a rod of alabaster into the delivery pipe, and, by periodically weighing it, to determine, by means of the quantity of calcium sulphate solved, the amount of water which has passed through. (Edison availed himself of a similar procedure in his first "electricity counter" or registering apparatus [measuring instrument], in which, zinc being used as an electrode, the quantity of the zinc, solved by a secondary current, served to calculate the total of the current which has passed

through.) Obviously, a practical application of this latter procedure is out of the question, since any water saturated with gypsum can hardly be accepted as fit either for drinking or feeding of boilers or any of the generality of industrial purposes.

Thus, in the main only two systems are deserving our serious attention, the "piston water-meter" and the "speed or wheel water-meter." The space meter has the undoubted advantage of greater reliability; theoretically, I can imagine the piston so tightly fitting in its operation that a loss of water seems quite impossible. Although in practice, through the required play and gradual wear, a certain looseness of action and consequent small losses may arise, they are in no way comparable with the fundamental defect of the "speed meters," which, whenever the frictional resistance of the main shaft and of the means of transmission of the movement is greater than the power yielded by the passing current of water, must limit themselves to a certain trifling quantity of water passing through in a unit of time. This technical superiority, however, is counterbalanced by an economical drawback, in so far as, up to the present, the piston water-meters are considerably more expensive, both as regards the original cost of manufacture and also that of maintenance, so that the amounts for interest, maintenance, and amortization might possibly exceed the sums paid for the water measured.

It may be mentioned as one of the advantages of the winged-wheel water-meters that whenever they are out of order and unable to register the water may still pass through, which is not the case with piston water-meters. It has been shown that in this manner it might occur that in very urgent cases, such as fire, the water supply would be cut off. We cannot altogether deny this; on the other hand, it should not be forgotten that the piston water-meter, when ceasing to work, by the very fact of the water current being stopped likewise, rouses attention, and thus all the sooner calls for help. But it should be noticed, also, that with piston water-meters with only one cylinder it might happen that the water flows through the meter although the apparatus is not working, and the amount of water consequently remains unregistered. Thus, now, we should put the question whether space meters or speed meters deserve the preference; but in reality we cannot answer with a simple yes or no, as we shall have to consider a whole range of possible contingencies.

We may, for instance, have a spring yielding such a volume of

water, with natural fall, that it cannot be consumed by the community concerned; in this case it would obviously be useless to put up water-meters. But it will more frequently happen that the quantity of water on hand is a smaller one, or that pumps have to be applied to raise the water. Besides, the amounts of water may become smaller and smaller, and the expense of raising it larger and larger.

In accordance with these different contingencies, we shall thus have to apply either no water-meters at all, or wheel water-meters or piston water-meters; and probably, in the course of time, in proportion as matters grow more complicated, as will undoubtedly be the case in large towns, a gradual transition will be effected from the wheel meter to the piston water-meter. But up to the present day, as far as I can judge, the prospects of such a change are extremely small. It is true that in France piston water-meters greatly predominate (because the water supplies, generally speaking, are in the hands of private companies which try to obtain as high rents as possible). On the other hand, in Germany, Austria, etc., wheel water-meters are used almost to the exclusion of all others. In our remarks we shall generally deal with wheel water-meters.

The principle with all remains the same. A winged wheel, similar to Woltmann's hydrometric wing, is set in motion by the passing water, and the transmission to the indicating device is then effected by means of a worm and wheel or pinion and wheel. If a division was desired, we might form them in two groups: First, water-meters with laterally relieved pivot, in which the water all around, being evenly distributed in a number of jets, enters the wheel chamber, by which means a lateral friction and wearing of the pivot is avoided—the water-meters of Siemens, Meinecke, Valentin, Leopolder are of this class; the second class being formed by the water-meters with one-sided strain upon the pivot, in which the water, in a single full jet, flows past the wheel, thereby exerting a lateral pressure upon the main shaft. This group, with reference to the best-known water-meter, might be called the Faller group, in which also the water-meters of Dreyer, Rosenkranz, and Droop should be included; whereas the former group, after a celebrated and very popular apparatus, may be designated as the Siemens group.

The advantage of the former class consists in the smaller wear of the main shaft and the larger sensitiveness and more permanent accuracy which it involves. Its disadvantage consists in the larger

loss of pressure, because the division of the water into a number of jets causes a larger frictional resistance, and, in consequence, a smaller working power of the water-meter.

Independently from the previous division, we can further distinguish the so-called wet-running and the so-called dry-running water-meters, or those in which the whole of the counting apparatus, together with the hands, works under water, and those in which the latter portions are separated from the water chamber by a stuffing-box, so that the real work of transmission takes place under water. The advantage of the former group consists in the absence of friction from the stuffing-box, which, again, generally speaking, involves a greater sensitiveness. Opposed to this are the following drawbacks: The dial, especially with unclean water and dead water conduits, soon gets turbid, and, if consisting of metal, becomes easily oxidized and illegible. Moreover, in the upper portion of the meter there easily forms a stagnant pool, which is most adapted for the propagation of bacteria, and the more so the more a circulation of the transmitted water is prevented by a perfect encasement. Thirdly, by strong and sudden pressures the glass may easily be broken.

Though most mains have a statical pressure of no more than 3, 5, or 8 (in Switzerland up to 15 and more) atmospheres, yet, by sudden closing of valves, hydrants, etc., sudden pressures of much larger force may occur. Thus, also, in this respect, we must make our choice according to circumstances, without too one-sidedly deciding for any one system in particular.

Having thus far given you a short survey of the present position of the water-meter question, I will now proceed to describe, in particular, "Schinzel's ebonite water-meter," the manufacture of which I have undertaken.

You will at once infer from the designs that Schinzel's water-meter belongs to the Siemens class, and has a laterally relieved wheel shaft. It can be constructed either as a wet- or as a dry-running meter. Fig. 261 (wet-runner) shows that Schinzel's ebonite water-meter has but two chief parts—the outer metallic casing, with locking device, and the inner or wheel-train compartment, enclosed by the former.

The outer casing has two horizontal arms, or portions, serving for insertion into the main, and provided either with a screw-thread or with flanges (according to the German models or the model of the city of Vienna).

The inlet portion, previous to its entrance into the cylindrical portion of the outer casing which receives the wheel-train compart-

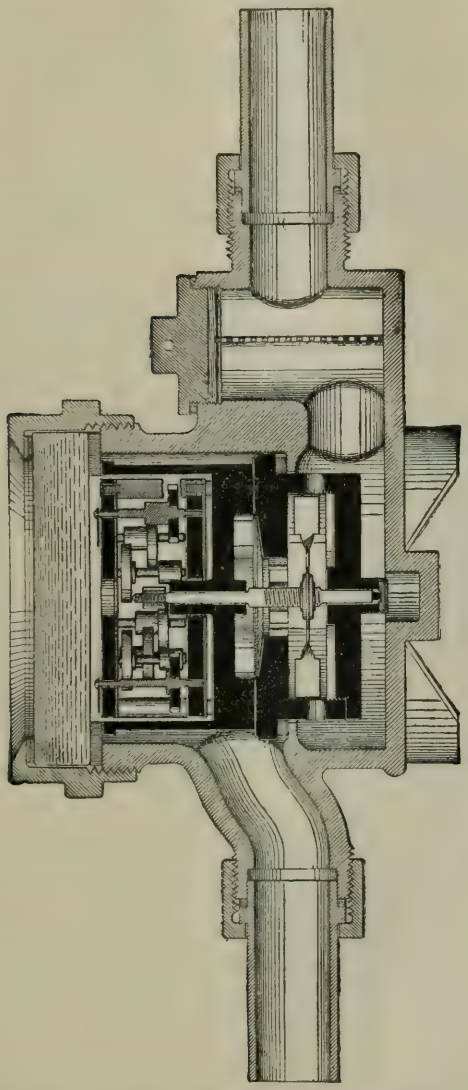


Fig. 261.

ment, widens out into the straining vessel, containing a removable sieve or strainer, and being above closed by a tightly fitting cap.

The inner hollow cylinder of the outer casing, at about one-third of its height, has a circumferential projecting edge, serving

as a support for the wheel-train compartment, and at the same time as a partition between the lower and upper water compartments.

Beneath this projecting edge is fitted the inlet portion ; above it, the outlet portion. The wheel-train compartment rests, by means of a shoulder, on this projecting edge, and is pressed down upon it by the lid of the casing and the intervening pane of thick plate glass.

The wheel-train compartment has two divisions, the lower one, which is shut off by a screw-lid and receives the winged wheel, being provided with the star-shaped cover; and the upper one,

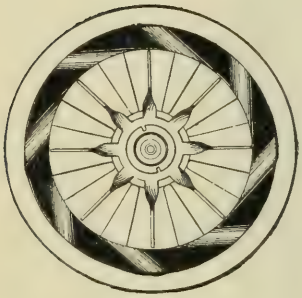


Fig. 262.

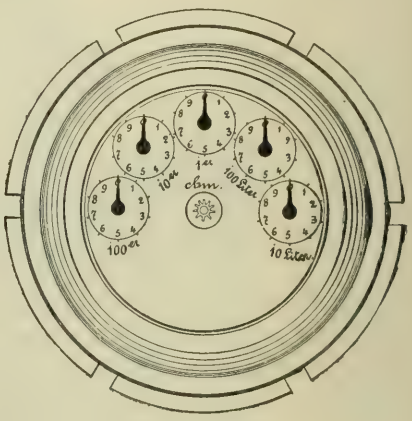


Fig. 263.

containing the inlet and wheel train, and communicating with the former by a central aperture.

The wheel shaft is made of delta metal; it turns with an ebonite pivot in polished carnelian bearings, and carries at its upper end a gear engaging the first of the cog-wheels.

The lower wheel compartment is of the smallest possible size, so as to allow only just the necessary space for the turning of the winged wheel (Fig. 262). Thus even the very smallest quantities of water will affect the wheel.

The speed having, by means of suitably geared wheels, been reduced to the desired extent, the movement is transmitted from the first system of wheels to the registering wheels, which, on their axles above, are provided with dials, indicating the consumption of water in decimal values—*i.e.*, in decalitres, hectolitres, cubic-litres, etc. (Fig. 263).

The dry-running water-meter (Fig. 264) differs from the wet-running one only in this, that the wheel-train compartment con-

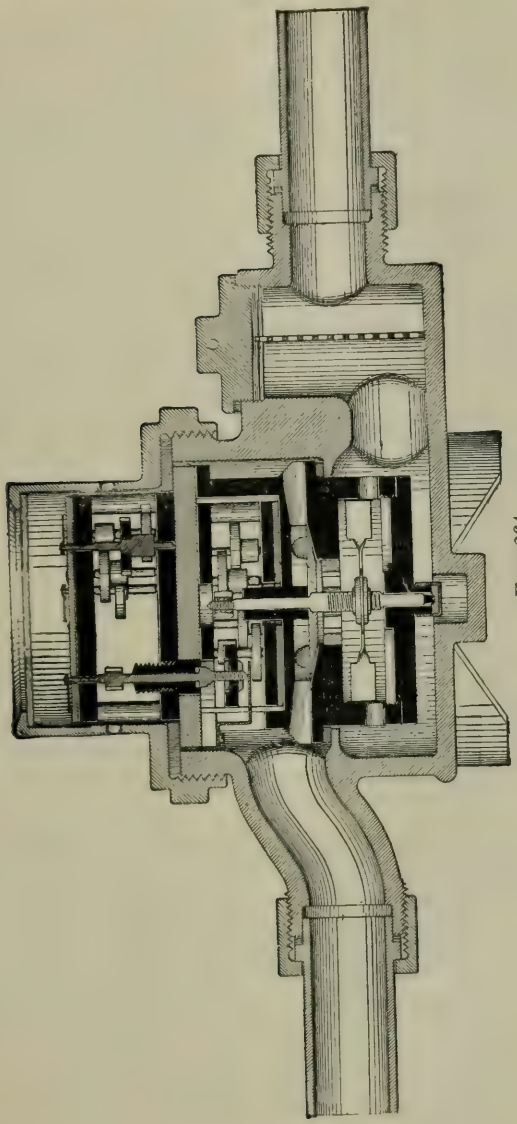


Fig. 264.

sists of three divisions, as the inlet wheels, which are separated from the cog-wheels, are arranged above them, and the movement is transferred by a longer axle which ends in a stuffing-box. By

reason of this arrangement, the registering wheel train as well as the dial and the hands are kept dry. The course of the water through the water-meter is as follows:

It enters by the inlet piece, passing thence through the straining vessel, which retains all impurities such as particles of wood, bark, hemp-fibre, small particles of lead, etc., and then flows into the lower annular cylindrical space. Thence it passes through the oblique openings of the wheel-train compartment into the wheel compartment, tangentially striking the wings of the wheel, which are thereby set in motion, and then obliquely ascending to the centre of the cover, so as to reach the upper part of the wheel-train compartment. After this it passes to the upper annular cylindrical space of the outer casing, and is discharged at the outlet.

The upward movement of the water in the wheel compartment partially relieves the pivot in a vertical sense, proportionately to the speed of the flowing water, and thus reduces the wear of the pinion; the latter, in consequence of the resinous properties of ebonite, is, so to speak, a self-lubricating one, which wears very little, and, owing to the great difference in the hardness of the materials, does not affect the carnelian bearings in the least.

The following tables give the results obtained with two of Schinzel's ebonite water-meters by actual test in the water-meter test station of the city of Vienna, one of which, after within a twelve-month transmitting the enormous volume of nearly five thousand cubic metres of water (for which, ordinarily, a space of from five to eight years would be required), proved on a second trial to be not only without a fault, but even to have increased in sensitiveness.

Figures 265 and 266, for the sake of fuller illustration, give these results also graphically. It will be seen that, up to a consumption of sixty litres of water per hour, the greatest deviation, in both the wet-running and the dry-running water-meter, did not exceed $\mp$ 2 %, and that with the dry-running meter it generally amounted to only some tenths per cent. But the point to be especially borne in mind is this, that in Schinzel's ebonite water-meter this sensitiveness and exactness are *permanent.*

The advantages of Schinzel's ebonite water-meter may be summed up briefly as follows:

1. The outer metal casing is heavily tinned on the interior, whereby a formation of verdigris in this part is rendered absolutely impossible.

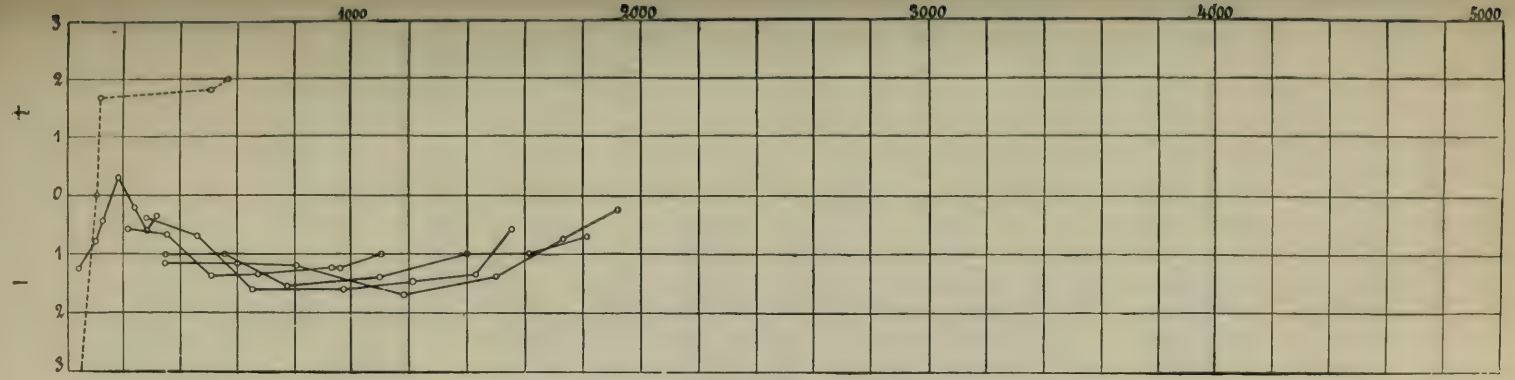


FIG. 265.

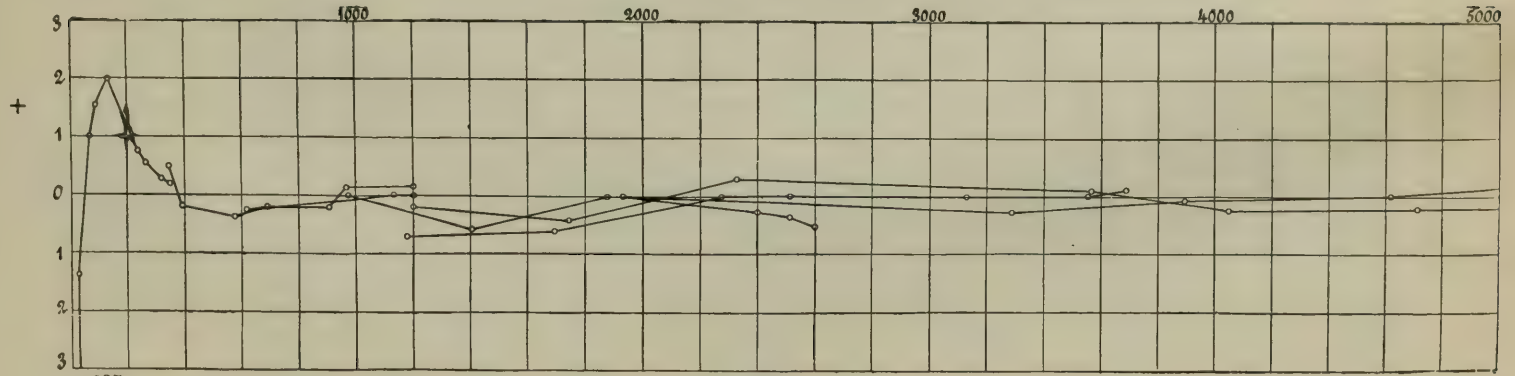


FIG. 266.

2. The straining vessel has a large sectional area, whereby any appreciable loss of pressure is avoided, while the sieve, or strainer, without removal of the water-meter from the conduit pipe, may be taken out and cleansed.

3. The wheel-train compartment can, without requiring the water-meter to be taken apart, be exchanged for another one, and it can be conveniently turned round in the outer casing, for reading the indications, without either operation interfering with the correct indication.

4. The working compartment consists entirely of ebonite, which neither suffers from the contact with water nor collects incrustation, thus securing the permanency of the sectional area of the boring, and thereby of the results of the measurements.

5. The wheel compartment fits closely around the wheel, and the star-shaped cover almost perfectly counteracts the whirling movements of the water, thus rendering the results of measurement, with most discrepant consumptions, very uniform.

6. The bearings of the ebonite pivot on polished carnelian greatly reduces the friction, and causes great sensitiveness with a minimum amount of wear.

7. The shaft of the winged wheel, with the water symmetrically distributed around it, is thoroughly eased laterally.

8. Also vertically, it is partially relieved from strain by the upward current of the water; both contribute to an easy motion and greater sensitiveness of the water-meter.

9. All the wheels are made of ebonite, all the gears of delta-metal; hence also, in their case, the friction and wear are very trifling, and a clogging up, through oxidation, is quite out of the question.

10. Through the tinned casing, and a very extensive use of ebonite, and of the almost immutable delta-metal, the *hygienic* properties are put on a most reassuring and reliable basis.

Everything tends to prove that Schinzel's ebonite water-meter offers a great number of advantages which no other system could possibly equal, much less surpass.

Copied from the test-book of the municipal water-meter test station of Vienna.

VIENNA, *October* 1, 1890.

Date.	Water-meter. System.	Water-meter. No.	Diameter.	Atmospheric pressure.	Orifice.	Reading. Before the trial.	Reading. After the trial.	At the Trial. The water-meter showed	At the Trial. Measured in the vessel.	Error.	Error. Per cent.	Time. Hours.	Time. Minutes.	Time. Seconds.	Observations.
	Ebonite, Schinzel's Patent.		10 mm.	5	5‴	5,000	6,000	1,000	1,002	—	0.2	..	31	0	Wet-runner.
				4	5‴	.....	7,000	1,000	1,008	—	0.8	..	35	0	
				3	5‴	.....	8,000	1,000	1,013	—	1.3	..	40	20	
				2	5‴	.....	9,000	1,000	1,016	—	1.6	..	51	0	
Oct. 2				1	5‴	.....	10,000	1,000	1,012	—	1.2	1	14	0	
				0.5	5‴	.....	11,000	1,000	1,012	—	1.2	1	40	0	
3				0.2	5‴	.....	12,000	1,000	1,012	—	1.2	2	51	0	
4				5	4‴	12,000	13,000	1,000	1,007	—	0.7	..	33	0	
				4	4‴	.....	14,000	1,000	1,010	—	1.0	..	37	0	
				3	4‴	.....	15,000	1,000	1,010	—	1.0	..	43	0	
				2	4‴	.....	16,000	1,000	1,013	—	1.3	..	54	30	
5				1	4‴	.....	17,000	1,000	1,015	—	1.5	1	17	20	
				0.5	4‴	.....	18,000	1,000	1,010	—	1.0	1	47	0	
6				0.2	4‴	.....	19,000	1,000	1,010	—	1.0	2	45	0	
7				5	3‴	19,000	20,000	1,000	1,006	—	0.6	..	38	30	
				4	3‴	.....	21,000	1,000	1,012	—	1.2	..	42	0	
				3	3‴	.....	22,000	1,000	1,013	—	1.3	..	49	30	
8				2	3‴	.....	23,000	1,000	1,014	—	1.4	1	1	30	
				1	3‴	.....	24,000	1,000	1,015	—	1.5	1	32	0	
				0.5	3‴	.....	25,000	1,000	1,007	—	0.7	2	10	0	
9				0.2	3‴	.....	26,000	1,000	1,004	—	0.4	3	39	0	
				5	2‴	26,000	27,000	1,000	1,010	—	1.0	..	54	0	
10				4	2‴	.....	28,000	1,000	1,012	—	1.2	1	1	30	
				3	2‴	.....	29,000	1,000	1,012	—	1.2	1	3	0	
11				2	2‴	.....	30,000	1,000	1,013	—	1.3	1	30	0	
				1	2‴	.....	31,000	1,000	1,013	—	1.3	1	56	0	
				0.5	2‴	.....	32,000	1,000	1,006	—	0.6	2	51	0	
12				0.2	2‴	.....	33,000	1,000	1,005	—	0.5	4	28	40	
13				5	1‴	33,000	34,000	1,000	1,004	—	0.6	3	15	0	
				4	1‴	.....	35,000	1,000	1,006	—	0.6	3	37	0	
14				3	1‴	.....	36,000	1,000	1,002	—	0.2	4	12	0	
				2	1‴	.....	37,000	1,000	998	+	0.2	5	16	0	
15				1	1‴	.....	38,000	1,000	1,005	—	0.5	7	19	0	
16				0.5	1‴	.....	39,000	1,000	1,009	—	0.9	9	10	0	
17–18				0.2	1‴	.....	40,000	1,000	1,012	—	1.2	14	44	0	50–55 sec., 1 litre.

After this water-meter for a full twelve-month had done service in the premises of a town school, and had transmitted as many as 4,653,850 litres of water, it was tested anew in the station and yielded the following results:

Date.	Water-meter. System.	Water-meter. No.	Diameter.	Atmospheric pressure.	Orifice.	Reading. Before the trial.	Reading. After the trial.	At the Trial. The water-meter showed	At the Trial. Measured in the vessel.	Error.	Error. Per cent.	Time. Hours.	Time. Minutes.	Time. Seconds.	Observations.
				1	1‴	3,850	4,900	1,050	1,033	+	1.7	8	19	0	28½ sec., 1 litre.
				½	3‴	5,000	6,000	1,000	982	+	1.8	2	0	0	
				¼	5‴	6,000	7,000	1,000	980	+	2.0	1	44	0	
						7,000	7,400	400	400	..	0.0	8	55	0	80 sec., 1 litre.
						7,400	8,000	600	625	—	4.1	21	20	0	120 sec., 1 litre.
						8,000	8,500	500	570	—	14.0	26	24	0	164 sec., 1 litre.
						8,500	9,000	500	730	—	40.0	29	10	0	4 min., 15 sec., 1 litre.

Copied from the test-book of the municipal water-meter test station of Vienna.

VIENNA, *December* 10, 1891.

DATE.	WATER-METER. System.	WATER-METER. No.	Diameter.	Atmospheric pressure.	Orifice.	READING. Before the trial.	READING. After the trial.	AT THE TRIAL. The water-meter showed.	AT THE TRIAL. Measured in the vessel.	ERROR. −	ERROR. +	ERROR. Per cent.	TIME. Hours.	TIME. Minutes.	TIME. Seconds.	OBSERVATIONS.
Dec. 1	Schinzel...	4,003	13 mm.	5	6‴	4,000	5,000	1.000	1,002	—		0.2	..	11	30	Dry-runner.
	.....	.....	.....	4	6‴	.....	6.000	1,000	1,002	—		0.2	..	12	40	
	.....	.....	.....	3	6‴	.....	7,000	1,000	1,002	—		0.2	..	14	50	
	.....	.....	.....	2	6‴	.....	8,000	1,000	999		+	0.1	..	16	40	
	.....	.....	.....	1	6‴	.....	9,000	1,000	998		+	0.2	..	25	30	
	.....	.....	.....	0.5	6‴	.....	10,000	1,000	1,004		−	0.4	..	34	30	
	.....	.....	.....	0.2	6‴	.....	11,000	1,000	1,002	—		0.2	..	49	50	
2	.....	.....	.....	5	5‴	11,000	12,000	1,000	998		+	0.2	..	11	50	
	.....	.....	.....	4	5‴	.....	13,000	1,000	1,000	..		0.0	..	13	0	
	.....	.....	.....	3	5‴	.....	14,000	1,000	1.001	—		0.1	..	15	30	
	.....	.....	.....	2	5‴	.....	15,000	1,000	1,002	—		0.2	..	18	20	
	.....	.....	.....	1	5‴	.....	16,000	1,000	1,000	..		0.0	..	26	0	
	.....	.....	.....	0.5	5‴	.....	17,000	1,000	1,006	—		0.6	..	35	30	
	.....	.....	.....	0.2	5‴	.....	18,000	1,000	1,007	—		0.7	..	51	30	
3	.....	.....	.....	5	4‴	18,000	19,000	1.000	999		+	0.1	..	16	20	
	.....	.....	.....	4	4‴	.....	20,000	1,000	1,000	.		0.0	..	16	50	
	.....	.....	.....	3	4‴	.....	21,000	1,000	1,000	..		0.0	..	19	10	
	.....	.....	.....	2	4‴	.....	22,000	1,000	1,000	..		0.0	..	24	0	
	.....	.....	.....	1	4‴	.....	23,000	1,000	1.000	..		0.0	..	32	0	
	.....	.....	.....	0.5	4‴	.....	24,000	1,000	1,005	−		0.5	..	42	30	
	.....	.....	.....	0.2	4‴	.....	25,000	1,000	1,000	..		0.0	1	1	30	
4	.....	.....	.....	5	3‴	25,000	26,000	1,000	1,004	−		0.4	..	23	0	
	.....	.....	.....	4	3‴	.....	27,000	1,000	1,003	−		0.3	..	24	0	
	.....	.....	.....	3	3‴	.....	28,000	1,000	1,002	−		0.2	..	25	0	
	.....	.....	.....	2	3‴	.....	29,000	1,000	1,000	..		0.0	..	31	0	
	.....	.....	.....	1	3‴	.....	30,000	1,000	1,000	..		0.0	..	50	0	
	.....	.....	.....	0.5	3‴	.....	31,000	1,000	1,000	..		0.0	..	53	30	
	.....	.....	.....	0.2	3‴	.....	32,000	1,000	1,004	−		0.4	1	37	30	
5	.....	.....	.....	5	2‴	32,000	33,000	1,000	998		+	0.2	..	50	0	
	.....	.....	.....	4	2‴	.....	34,000	1,000	998		+	0.2	1	0	30	
	.....	.....	.....	3	2‴	.....	35,000	1,000	1,002	—		0.2	1	3	30	
	.....	.....	.....	2	2‴	.....	36,000	1,000	1,002	—		0.2	1	27	30	
6	.....	.....	.....	1	2‴	.....	37,000	1,000	1,004	—		0.4	1	42	0	
	.....	.....	.....	0.5	2‴	.....	38,000	1,000	1,001	—		0.1	2	32	0	
	.....	.....	.....	0.2	2‴	.....	39,000	1,000	995		+	0.5	2	54	0	
7	.....	.....	.....	5	1‴	39,000	40,000	1,000	997		+	0.3	2	54	0	
	.....	.....	.....	4	1‴	.....	41,000	1,000	996		+	0.4	3	14	0	
	.....	.....	.....	3	1‴	.....	42,000	1,000	994		+	0.6	8	14	0	
8	.....	.....	.....	2	1‴	.....	43.000	1,000	992		+	0.8	4	6	0	
	.....	.....	.....	1	1‴	.....	44.000	1,000	980		+	2.0	6	26	0	
9	.....	.....	.....	0.5	1‴	.....	45,000	1,000	985		+	1.5	8	41	0	
10	.....	.....	.....	0.2	1‴	.....	46,000	1,000	990		+	1.0	11	20	0	
	With throttled valve.					46.000	47,000	1,000	1,014	—		1.4	17	34	0	60 sec., 1 litre.
	With throttled outlet.					47,000	48,000	1,000	1,063	—		6.3	26	58	0	90–95 sec., 1 litre.
	With throttled outlet.					48,000	49,000	1,000	1.178	—		17.8	44	0	0	120–140 sec., 1 litre.
								The water-meter stops.								4 min., 1 litre.

DISCUSSION.

Mr. John M. Goodell.—It is interesting to note that the polished carnelian bearings and laterally undisturbed main shaft of the Schinzel water-meter have produced a mechanism which increases in sensitiveness under continued usage; but the author should not be permitted to believe that he is the only manufacturer who makes the claim that "everything tends to prove that the ebonite water-meter offers a great number of

advantages which no other system could possibly equal." Mr. Lux undoubtedly makes a good meter, but there are many others also; and to say that any one is better than others for practically all purposes is unwarranted in the judgment of the writer.

Most water-meters are used for the measurement of the water supplied to buildings of various sorts, and their object is simply to register the amount consumed on the premises, so that the owner will neither pay for more than his proper quantity, nor compel others to pay for his wasteful habits as is the case under the family rate system. The use of meters is largely brought about by our habit of wasting water, and to prevent waste we do not need expensive or absolutely accurate meters. For more than a year the writer has been in correspondence with water works officials in all parts of the country, and he believes that the most progressive superintendents are pretty generally in favor of a simple, inexpensive meter which need not be exact within four or five per cent. Absolute exactness costs altogether too much in a meter to make it financially suitable for general use. While it is true that we want the meter to tell us how much water we are using, we want it principally to prevent excessive waste, and a cheap meter will do this just as well as any expensive type with polished cornelian bearings and other luxurious trimmings.

To show what is meant, the experience of Atlanta, Ga., may be cited. According to official reports there were about 1,500 service pipes in that city in 1885. The city laid in then about a year's supply of coal. That was in March, when the average daily pumpage was nearly 6,000,000 gallons. A number of disastrous fires occurred, when the loss was largely increased by lack of water. So it was decided to meter the services. This was done. The year's supply of coal, based on the amount consumed in 1884, lasted about twenty-six months, and the amount of water used fell to about 1,500,000 gallons a day. The hydrant pressure rose, all the people had plenty of water, and the coal necessary to pump the 4,500,000 gallons of water that were previously wasted daily was saved to the tax-payers.

This shows that it is the moral influence of the meter which is its most valuable feature, as Mr. Robert Cartright has well said, and not its extreme accuracy.

DXXXIV.*

AN EVAPORATIVE SURFACE CONDENSER.

By James H. Fitts, Blacksburgh, Va.

(Late Member of the Society.) †

The condenser herein described was built at the Virginia Agricultural and Mechanical College at Blacksburgh, Va., after some observations were made on the rate of evaporation of water at different temperatures, and with a current of air passed over its surface. Its performance has been successful to such a degree that this paper is presented, in the belief that it will be of general interest to the profession, and that it gives a practical solution of the question of condensation of vapor with a small water supply. While it may meet with criticism for its crudities, the author hopes to avail himself of this to make good any deficiencies for a future meeting of the Society.

This condenser (Fig. 268) consists of two rectangular end chambers connected by a series of horizontal rows of tubes, each row of tubes immersed in a pan of water. Through the spaces between the surface of the water in each pan and the bottom of the pan above, air is drawn by means of an exhaust fan. At the top of one of the end chambers is an inlet for steam, and a horizontal diaphragm about midway causes the steam to traverse the upper half of the tubes and back through the lower. An outlet at the bottom leads to the air-pump.

The condenser, exclusive of connection to the exhaust fan, occupies a floor space of $5'\ 4\frac{1}{2}''$ x $1'\ 9\frac{3}{4}''$, and is $4'\ 1\frac{1}{2}''$ high. There are 27 rows of tubes, 8 in some, and 7 in others; 210 tubes in all. The tubes are of brass, No. 20 B. W. G., $\frac{3}{4}''$ external diameter and $4'\ 9\frac{1}{2}''$ in length. The cooling surface (internal) is 176.5 square feet.

There are 27 cooling pans, each $4'\ 9\frac{1}{2}''$ x $1'\ 9\frac{3}{4}''$, and $1\frac{7}{16}''$ deep. These pans have galvanized iron bottoms, which slide into hori-

* Presented at the Chicago meeting (August, 1893) of the American Society Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

† The author lost his life in a railway accident while on his way to the meeting to present his paper. Suitable references were made at the session at which it was presented on his behalf.

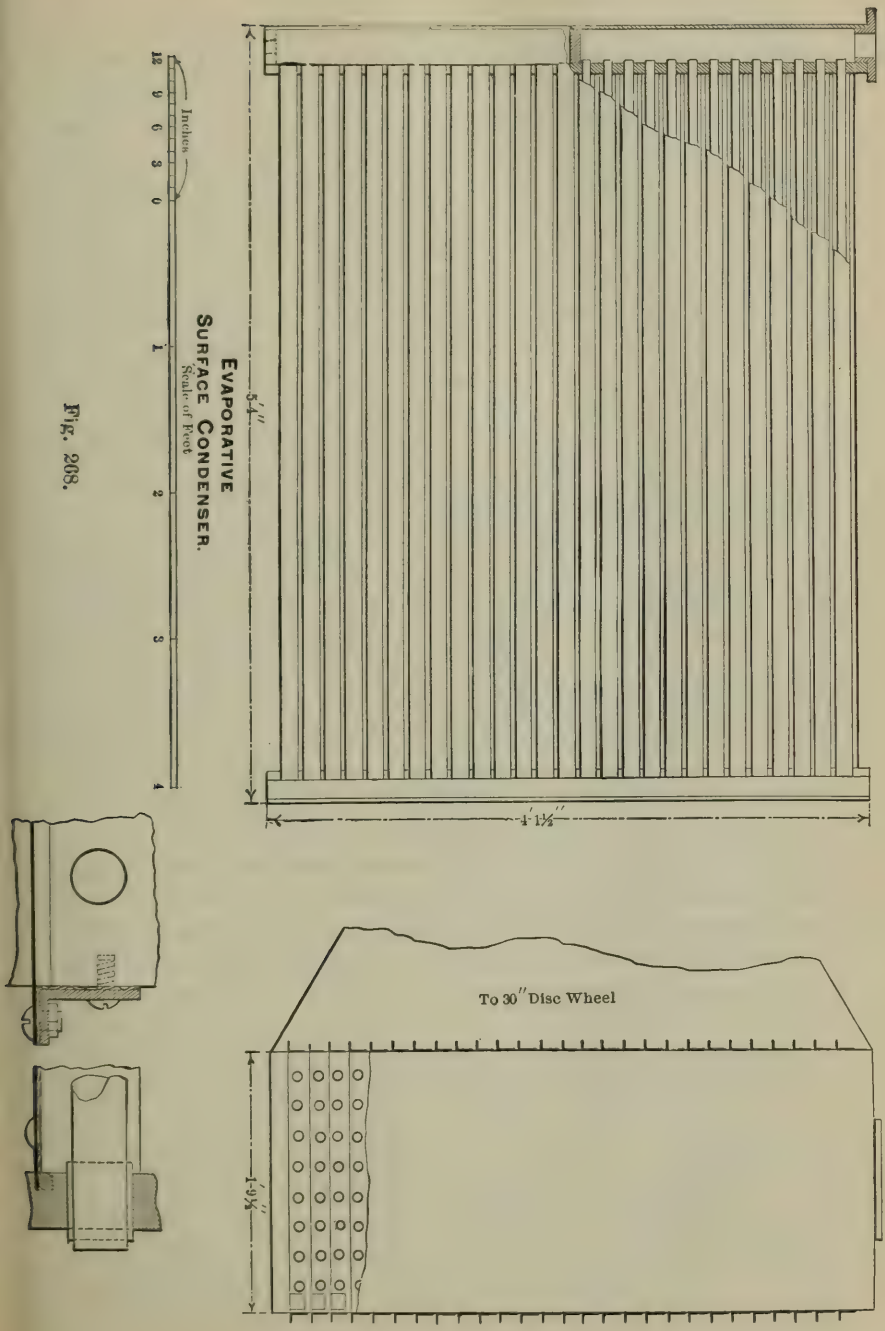

Inches
12 9 6 3 0
1
2
3
4
Scale of Feet
EVAPORATIVE
SURFACE CONDENSER.
5'-4"
4'-1½"
To 30" Disc Wheel
1'-9¼"

Fig. 268.

zontal groves $\frac{1}{4}''$ wide and $\frac{1}{4}''$ deep, planed into the tube sheets. Wooden strips are fitted into the grooves below the bottoms. The tube sheets form the ends, and angle irons $1\frac{3}{8}'' \times \frac{3}{4}'' \times \frac{1}{8}''$ bolted to the galvanized bottoms, the joints packed with wooden strips, form the sides. The total evaporating surface is 24.8″ square feet. Water is fed to every third pan through small brass cocks, and $1\frac{1}{4}''$ overflow pipes feed the rest. (The drawing does not show the method of water supply.)

A wood casing connects one side with a 30″ Buffalo Forge Co.'s disk wheel. This wheel is belted to a 3″ x 4″ vertical engine.

The air pump is $5\frac{3}{4}''$ diameter with a 6″ stroke, is vertical and single acting. This pump acts imperfectly, due partly to a defective cylinder casting, and can produce a vacuum of only 24 inches of mercury when steam is not admitted to the condenser. As the normal barometer reading is 28 inches, this indicates a residual air pressure of 4 inches.

The action of this condenser is clear. The passage of air over the water surfaces removes the vapor as it rises, and thus hastens evaporation. The heat necessary to produce evaporation is obtained from the steam in the tubes, causing the steam to condense. It was designed for the college shop engine, to condense 800 pounds steam per hour, and give a vacuum of 22 inches, with a terminal pressure in the cylinder of 20 pounds absolute; but it was found practically impossible to get the long exhaust pipe air-tight, on account of its numerous connections. Direct connection was therefore made with the boiler. A number of runs of several hours' duration have been made with a boiler pressure of 60 to 70 pounds. The cooling water was run into a barrel placed overhead, and drawn from the barrel. The water of condensation was weighed. The following table gives average results:

Boiler pressure, lbs. per sq. in. per gauge.	Temperatures in Fahr. Degs.							Working strokes of air pump.	Revolutions of exhaust fan per min.	Velocity of air in feet per min.	Quantity of air moved in cu. ft. per min.	H. P. expended in driving fan.	Barometer in inches.	Cooling water used per hour in pounds.	Steam condensed per hour in pounds.	Vacuum in inches of mercury.	Vacuum reduced to barometer at 30.
	Steam.	Cooling Water (initial).	Water in pans above diaphragm.	Water in pans below diaphragm.	Hot well.	Air.	Dew point.										
65	311	60	140	115	149	70	62	90	740	2,300	6,500	$\frac{1}{4}$	28	1,350	900	$16\frac{1}{4}$	$18\frac{1}{4}$

The overflow pipes for regulating the supply of water were found to be too small, so that at times some pans would be too full, causing waste of water over the edges, and at others the tubes would be uncovered, with reduction in efficiency. This loss of cooling water will account for the amount being so much in excess of the water of condensation. The amount of steam condensed, if there had been no waste of water, would have been about 30 pounds less than that shown.

Accurate analysis of the transfer of heat could not be made on account of this waste. An approximate analysis, however, may be based on information obtained from the curve of evaporation given below.

Heat in 1 lb. steam at 311° = 1208.3 B. T. U.
" " " " water at 149° = 149.
Heat rejected by 1 lb. steam = 1208.3 − 149 = 1059.3.

Of each pound of water evaporated in the condenser, probably $\frac{5}{7}$ is at 140°, and $\frac{2}{7}$ at 115°.

Heat absorbed by $\frac{5}{7}$ lb. water in being warmed from 60° to 140° = 57.1.

Heat of vaporization of $\frac{5}{7}$ lb. = 725.5.

Heat absorbed by $\frac{2}{7}$ lb. water in being warmed from 60° to 115° = 15.7.

Heat of vaporization of $\frac{2}{7}$ lb. = 299.7.

Total heat absorbed by 1 lb. water
= 57.1 + 725.5 + 15.7 + 299.7 = 1098.

The cooling water required, then, is practically equal in amount to the steam used by the engine. And since consumption of steam is reduced by the application of a condenser, its use will actually reduce the total quantity of water required.

This condenser is still in a crude form, and there are many improvements to be made in it. One of these is obvious: to cool the water of condensation still further by passing it through an attachment similar to the usual type of surface condenser on its way to the air pump, through which the cooling water first circulates. Enough has been done, however, to demonstrate that it is of practical application in any situation, that it is not expensive to construct, is perfectly accessible for cleaning, requires small power to operate, and will give a vacuum of 20 to 22 inches. The floor space required is moderate.

A curve showing the rate of evaporation per square foot of

surface is given (Fig. 269), and also one showing the rate when a current of air of about 2,300 feet per minute *velocity* is passed

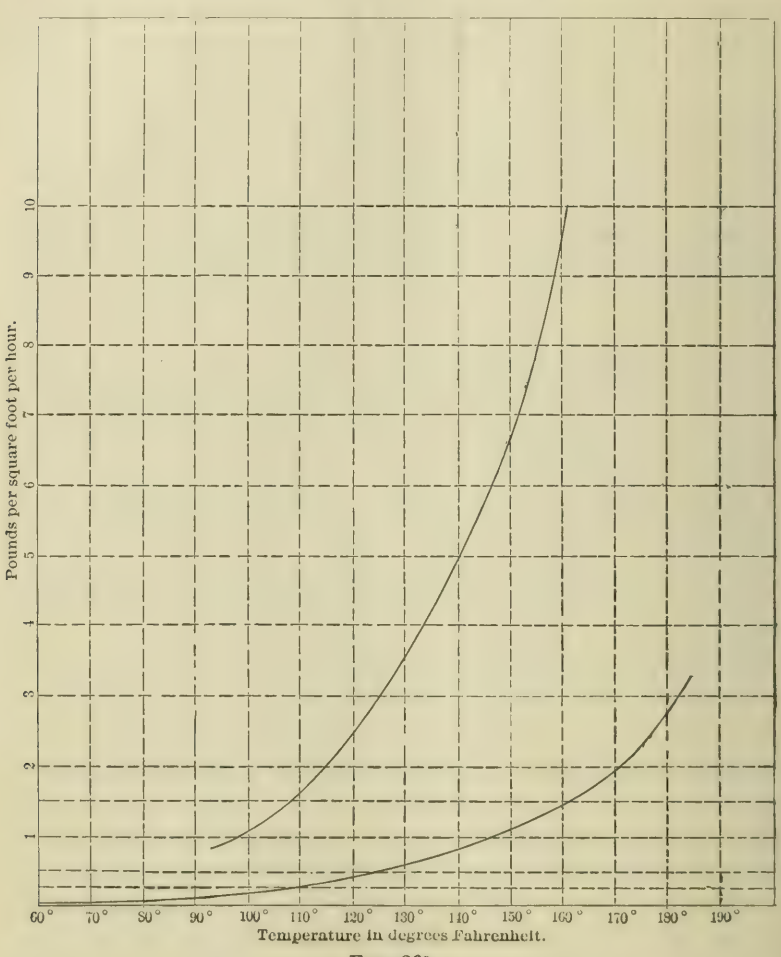


FIG. 269.

over its surface. The barometer reading averaged 27.9 inches during both sets of observations; the dew point for those in still air was 57°, and for those under a current of air, 68°.

DISCUSSION.

Mr. W. S. Aldrich.—I saw the surface condenser which is here shown in the diagrams and on which these tests were made. The remarkable performance of one pound of water, required

to condense one pound of steam, as given on the fifth page of the paper, should, I think, warrant us in paying considerable attention to this method for stationary engines, especially in electric light and power plants, in which it is usually possible to arrange for more or less extensive condensing systems as roof condensers, if such small supply of condensing water is required. These would resemble types of cooling apparatus as arranged for refrigerating machinery. In this way Mr. Fitts thought that evaporative surface condensers might find wide applications in large stationary power plants in increasing the economy at small expense for the condensing water required. The question of the practical application of this had been presented, I believe, to parties in Philadelphia, so that in a short time—at least, if all had been carried through as Mr. Fitts proposed—we would have had much valuable data in this direction. It is very unfortunate indeed that by the death of Mr. Fitts we have lost an earnest worker in this and other lines of engineering research in which he was engaged. Those of us here who knew him esteemed him very highly, socially and professionally.

DXXXV.*

THE COLLECTION OF DUST PRODUCED IN WORKSHOPS.

BY R. KOHFAHL, HAMBURG, GERMANY.

On the 20th day of February, 1883, the United States Patent Office granted to Mr. F. Prinz two patents relating to a "Dust Collector for Flour Mills."† A company was organized in Milwaukee which pushed the manufacture of the new machine with energy, and it was soon widely spread over those establishments of the country for which it was destined.

The modern flour-mills of the United States, following the example given by Hungary, had already succeeded at that time in producing a flour of very high standard by carefully cleaning and gradually reducing the wheat, and by amply purifying the middlings won by the breaks. In the cleaning and purifying process, machines were used in which the loosened particles of dust and bran were separated from the grains and the middlings by a current of air. The dust- or bran-laden air was then conducted into large dust-chambers, to reduce the velocity of the air to such a degree that the dust or the bran could fall down on the floor of the dust-room while the air would pass out through openings in the walls or in the roof. These dust-rooms only answered their purpose in a very imperfect manner ; they occupied a large space, required long air-pipes, and increased the danger to the mill from fire.

The Prinz dust-collector afforded a perfect filtration of the dust-laden air close to the places where it was produced. The cleaned air could be allowed to reënter the room from which it was taken, while the more or less valuable dust or bran was continually collected, and therefore ready for any further process. These advantages offered by the new machine were of such quality that it was rapidly introduced into most of the flour-mills of the country.

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

† U. S. Patents Nos. 272,473 and 272,474.

From the United States the Prinz dust-collector was exported to England and Germany. While in England, as in America, the flour-mills especially made use of the new machine, a greater field of application seemed to open for it in Germany. In this country the annoyance and injury from the dust, from which the workmen had to suffer in many industrial manufactories, were felt the more deeply since the Government constantly took pains to improve the lot of the working populace by special laws and by keeping the manufactories under the continual control of the state. Many engineers, therefore, were engaged in the problem of removing dust. Now, it is comparatively easy to suck up the dust by a pipe emptied by an exhauster at all the places where it is whirled up either by action of the hand or by moving machinery. But then the dust-laden air which is blown out of the fan has to be filtered in order to recover the dust. In most cases the dust is worth money, and this reason would suffice to cause an attempt to recover it; but even if the loss could be endured, it would not be convenient to blow out again the dust on the outside of the building. This could only be allowed in exceptional cases; for instance, where a factory lies quite isolated in the open country.

In Germany, therefore, a very good chance was given for the application of dust-collectors, and in consequence many new constructions were brought upon the market. It became evident, however, very soon, that different kinds of dust also required different handling. The very fine dust, for instance, in mills for Portland cement, for phosphate, for slag, or for chalk, is far more difficult in treatment than the dust of flour-mills, which for the greatest part is composed of the coarser particles of bran.

Such more difficult problems of dust-removing the Prinz collector has not quite been able to master, nor have the competing apparatuses given more satisfaction, which were but imitations of the former in part. To create a machine suitable also for the more difficult cases, it became necessary to find out the reasons for the failure of the known constructions, and then to invent a new one which would be free from the faults of the former. It is to a form of dust-collector which has stood the test on the most different problems of dust-removing, and which really may be called a *universal* apparatus that the author desires to call attention. Before, however, describing this dust-collector, the

author will try to explain the reasons of the limited applicability of the Prinz collector. Assuming as well known the construction and operation of this machine, two sections of which

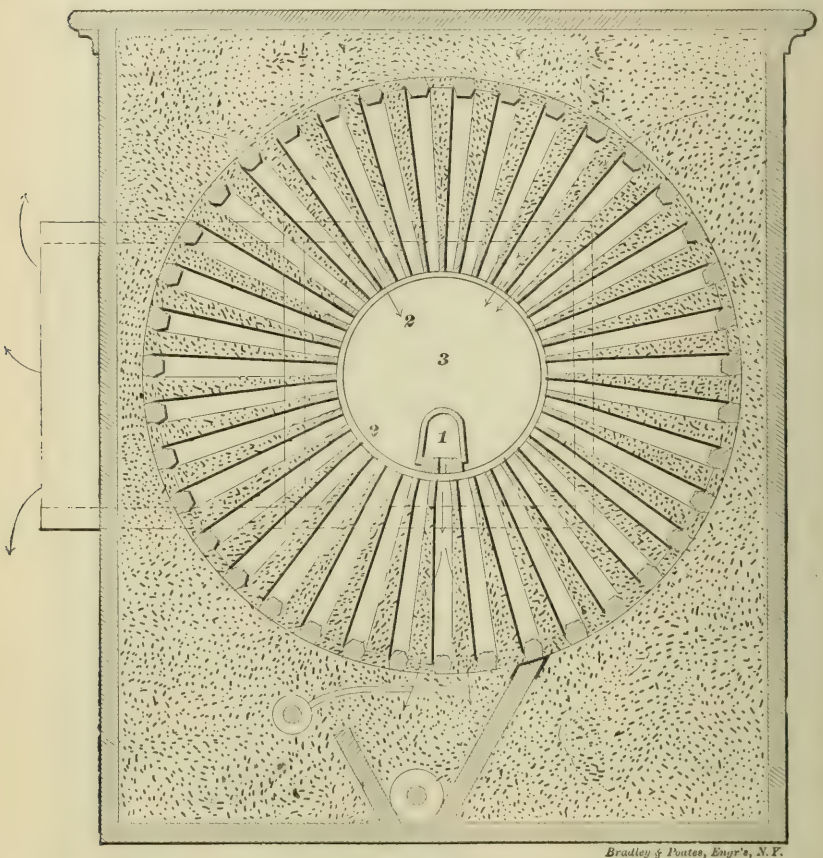


FIG. 270.

are given in Figs. 270 and 271, the author expresses his belief that the said reasons are to be found in—

1. The rotating cage ;

2. The arrangement of the filtering cells around a horizontal axis.

The strain of the ribs forming the cage or balloon changes at every rotation of the latter, and this circumstance must damage at last the coherence of the cage. The exact working of the ap-

paratus, and especially of the back-draught of air, depends upon the air-tight contact of the tube 1 with the inner ribs 2 of the cage. If these ribs cease to form an accurate cylinder the close contact is destroyed, and now more or less of the back-draught of air entering the tube 1 will be lost by leakage.

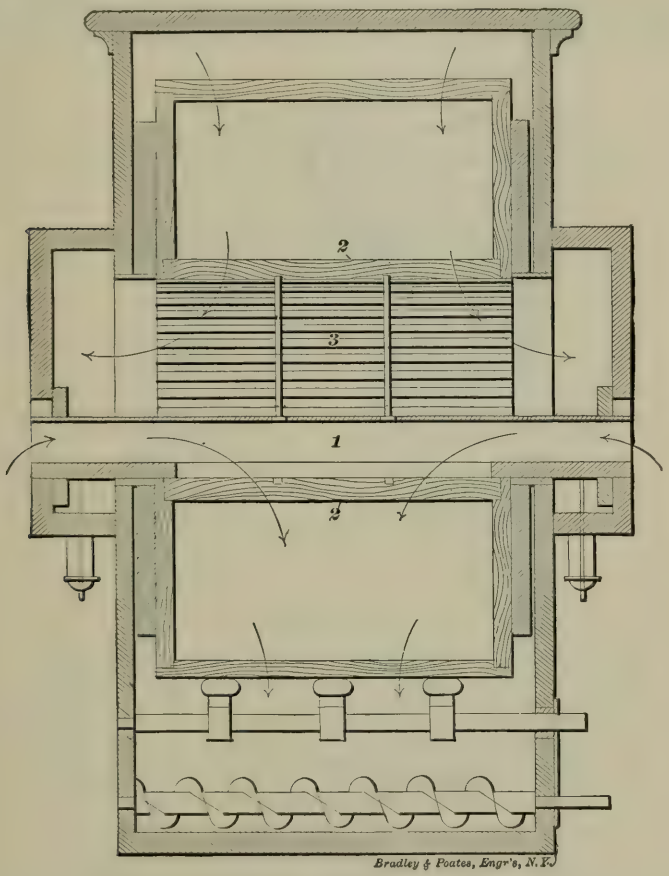


FIG. 271.

As to the arrangement of the filtering-cells around a horizontal axis, attention may be called to Fig. 270, where all the dust-filled space is punctuated. If the air in the apparatus is at rest for some time, every particle of dust will sink down under the influence of gravity until it hits on a solid wall. It will be seen that only from between three or five of the lower cells the dust can fall down unhindered into the bottom of the casing.

Between all the other cells, however, the falling dust will be stopped by the walls of the cells and will rest on the filtering cloth; moreover, in the cells of the upper part of the balloon dust will enter from outside of it. Of course, gravity will act in the dust-collector, when set at work, exactly in the same manner. The dust-laden air being drawn radially in between all the cells, gravity will diminish the obstruction of the flannel through the

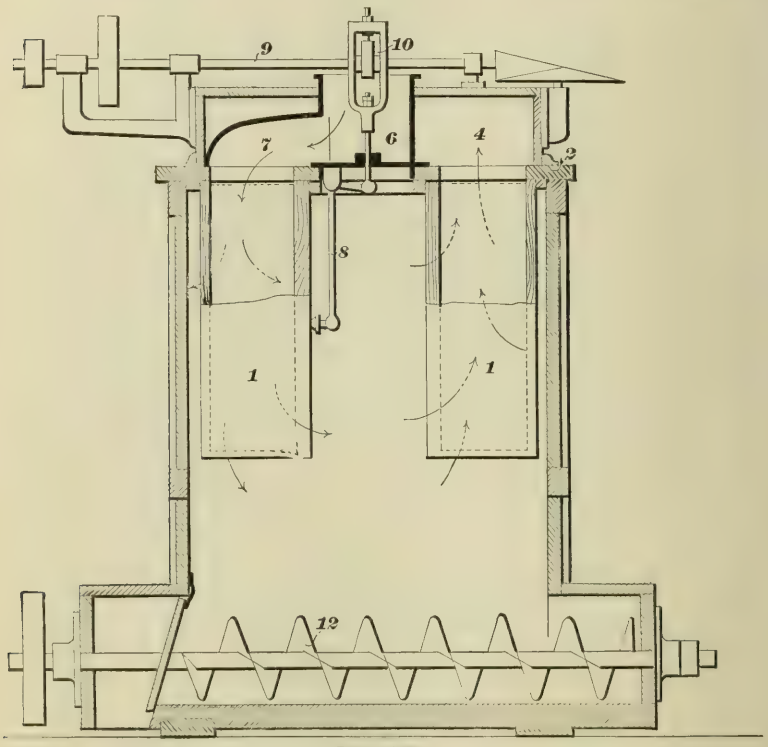


FIG. 272.

air-draught only at the few lowest cells, while at all the other cells it will increase the obstruction; and this increasing action will last for every cell until it has become again one of the lowest by the turning of the cage, *i.e.*, by far the greatest part of the time. Therefore the arrangement of the cells around a horizontal axis must be called an inappropriate one.

In the dust-collector here to be described,* which also uses a

* The machine which is shown in Figs. 272 to 276 was granted the United States Patent No. 361,711 on April 26, 1887.

back-draught of air for the cleaning of the cloth, the said disadvantages are totally avoided. The cloth-covered filtering-cells 1 are screwed unto a strong horizontal plate, 2, the openings of which, shown in Fig. 275, correspond exactly with the open upper ends of the cells 1. The plate 2 divides the lower part 3 of the chest from the upper part 4 of the same. The upper compartment 4 is connected by the pipe 5 with a suction-fan, and within

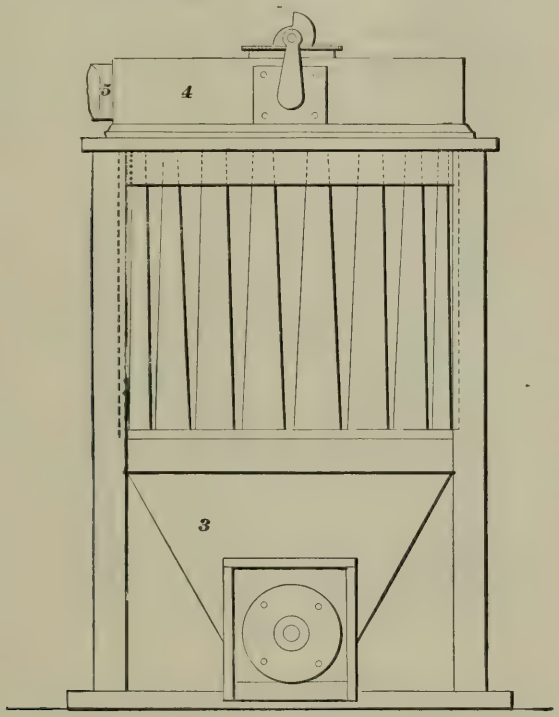


FIG. 273.

it there is placed a rotative hollow cylinder, 6, closed at the bottom and open at the top and extending through the upper horizontal wall of the compartment 4. From the said cylinder branches off a hollow arm, 7, having at its lower side an opening adapted to register with one of the cells, the flanged edges of the said opening being in sliding contact with the partition-wall 2. To the cylinder 6, a hammer 8, in the shape of a bent lever, is fixed, which is operated from the shaft 9 by a cam and the rod 10. The cylinder 6 is provided with teeth, the number of which

is equal to the number of cells; it is rotated by a pawl, 11, in such manner that the hollow arm 7 will always come to rest for a short time exactly over one of the cells. A creeper, 12, discharges continually the dust collecting in the chest.

The dust-laden air enters into the lower part of the chest by a pipe extending preferably into the cylindrical inner part of the cage. It then spreads radially between the cells and the lower part of the chest, and is filtered through the vertical flannel walls. As the exhauster blowing off the cleaned air evacuates the upper compartment 4, and indirectly also the lower compartment 3, fresh air from the surrounding room will, on account of its higher pressure, flow through the cylinder 6 and

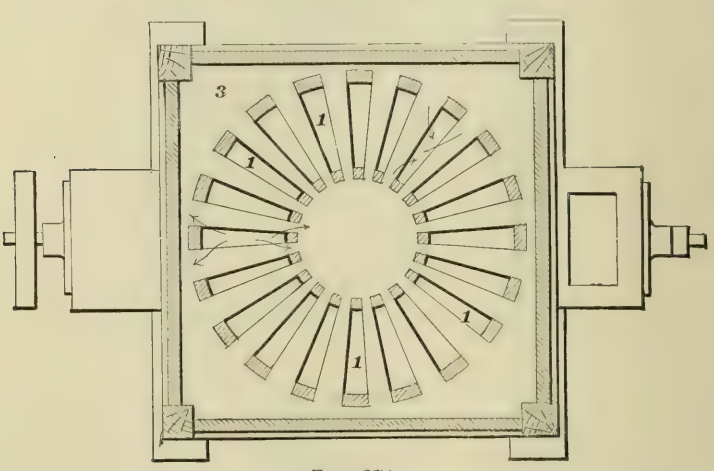


Fig. 274.

the hollow arm 7 into that single cell just covered by the said arm and pass through the cloth of this cell into the compartment 3. At the same time, the hammer 8 imparts several blows to the same cell, the cloth of which is thus perfectly cleaned by the combined action of the back-draught of air and the blows of the hammer. The arrows in the Figs. 272, 274, and 276 indicate the movement of the air.

It will be seen that in this dust-collector—

First, the cage is *fixed immovably* to a solid and stationary plate; that,

Secondly, the instrument for introducing the back-draught of air rests and slides on this stationary plate, and therefore can be kept easily and constantly *in air-tight contact*; that,

Thirdly, all the filtering-cells being arranged vertically, *the dust can fall down unstopped* from any point between the cells as well as from outside of them; and that,

Fourthly, gravity at each point *diminishes the obstructing action* of the dust-laden air, but *increases the cleaning action of the back-draught.*

These advantages account for the great superiority of the dust-collector herein described over the competing machines as proved by practical experience. The former reaches the same capacity with far less amount of filtering surface, and with the same surface does a great deal more work. The machine is at

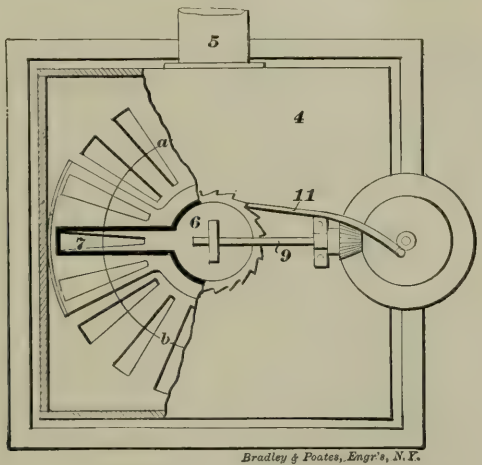
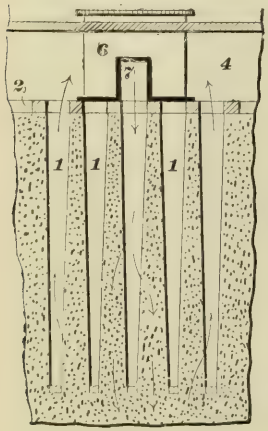


FIG. 275.

the present time built in four sizes, with wooden or iron chest, with or without an exhauster, with or without a mechanism for the automatical discharge of the dust, the latter being a creeper for the smaller sizes and a hopper-boy for the larger. The ribs of the cage are always made of wood on account of a more convenient fastening of the cloth; only in such exceptional cases as for the filtration of hot gas, iron is used also in this place, while at the same time the cloth is so impregnated as to become fire-proof. The chest is provided with large doors on each side through which the cage can be brought in conveniently. The cage itself is composed of four quadrants, from which each cell can be easily detached, thus facilitating the changing or repairing of single cells. The distance from one cell to the other is

wider than usual in order to prevent the choking of the intermediate spaces, and is particularly wide in dust-collectors for cotton mills, the dust of which is fibrous and inclines to cohere. Each dust-collector is also furnished with a vacuum-gauge, indicating the difference of the pressures of the air in front of the cloth and behind it. If the machine is started in the right way and not overcharged, the indication of this vacuum-gauge does not change at work. This could only happen if by any sudden overcharging of the collector the clogging of the cloth should be increased above the normal. It is, therefore, possible to convince one's self of the normal condition of the filtering surfaces without opening the doors of the chest, by only glancing at the vacuum-gauge. This renders very easy the control of the machine at work.



Section a.b.

FIG. 276.

A few words may be devoted, finally, to the theory of the apparatus. Suppose p_0 to be the atmospheric pressure, p_3 the pressure of air in the lower compartment 3, and p_4 that in the upper compartment 4; the dust will be pressed against the cloth with the pressure $p_3 - p_4$, and will be blown off from it with the pressure $p_0 - p_3$. Each cell being subjected to the obstruction by dust for a far greater time than to the cleaning back-draught, the pressure $p_0 - p_3$ must evidently be larger, mostly exceedingly larger than the pressure $p_3 - p_4$. The difference of these two pressures must be the greater the more difficult the handling of the dust to be operated proves. The experiments made with the Nagel & Kaemp dust-collector have taught that for the proportion $p_0 - p_3 : p_3 - p_4$ the figure 2 to 3 will suffice for the most easily operated kind of dust; as, for instance, the light bran from middlings-purifiers, while it must be raised to the value 5 to 10 for other kinds of dust, or even to 15 to 20 in the most difficult cases. The means for adjusting the said proportion exactly to that value, which experience has taught to be necessary for a certain kind of dust in order to keep the cloth clean, exist in the correct regulating of the quantity of dust-laden air offered to the collector. This quantity may be greater for coarse, heavy, or flat dust, and

must be diminished for fine, light, or globular dust. Of course, it is a matter of experience what quantity of dust-laden air the collector may be charged with, and, consequently, what cross-section must be given to the suction-pipe in each special case. The experiences gathered in this respect with the Nagel & Kaemp dust-collector extend very far, as the machine has already been tried and is now constantly working with excellent success in the following branches of industry: Flour-mills, pearling-mills, rice-mills, grain elevators, cement manufactories, potteries; mills for chalk, for Thomas-slag, for granulated slag, for phosphates and artificial dung; manufactories of soda, of oil, of conserves, of chocolate, for peeling coffee; jute manufactories, cotton-mills, paper manufactories, works for cleaning carpets or feathers, mills for sulphur, for tartar, for sugar, and for cinchona bark.

As the Nagel & Kaemp dust-collector up to date has been able to master such very different problems, and as it has consequently acquired great appreciation in Germany, the author hopes and thinks it likely that it will make its way in time also in the United States and elsewhere.

DISCUSSION.

*Mr. T. Clarkson.**—I had an opportunity to see one of these dust-collectors working in Germany. It was in a factory where they were conducting the manufacture of Portland cement in a dry way; that is, where it was crushed dry and it was mixed dry. The entire factory was entirely free from fine dust. I know that at the time I wore a dark suit of clothes, and I failed to detect the presence of any dust upon them when I came out. The collector is of small size. The machine I saw was made of iron and steel plate, which overcomes that objection to many collectors that they are liable to combustion. I have had experience with dust-collectors of the cyclone type, and they will not touch the finest dust; they only retain the granular portion, while the lightest material escapes through the top. This defect is entirely obviated by the machine described in Mr. Kohfahl's paper. It is the most efficient and the best of all dust-collectors that I have ever seen.

Mr. Alfred Vanderstegen.†—I beg to say a few words about a case in which the system of dust-collecting described in the paper was not convenient for its purpose and was not applied.

* Of Surrey, England. † Of Ghent, Belgium.

In a mill for the spinning of linen the cards or combs produce a great amount of dust, so that the air becomes irrespirable to an extent which compels the operatives to keep a handkerchief or other cloth before the mouth. The "Société de la Lys," of Ghent, which owns the largest flax spinning mills of Belgium, and perhaps of the European continent, has experimented with several systems to collect the dust from its cards, covering a considerable period of time.

The managers, after inspecting the filtering process belonging to the German apparatus, and exhibited in 1889 at Berlin, concluded that it would not succeed in their special case, for the reason that the air draught carries not alone the thin and light dust, but also a large amount of flocks or tufts of wasted flax, which ought to be collected. With the filtering process these flocks would adhere to the flannel of the filter and transform it into a sort of thick felt, which neither a back draught of air nor the repeated blows of the apparatus would remove. The collector used in the Belgium mill is quite different, and, so far as I know, is quite new, and has given very good results. The air is drawn in by the suction of fans through those parts of the machines where the dust is produced. Vertical flues fixed on the top of the machines convey the dust-laden air to a horizontal duct, whence the air passing through the fans is discharged into a rectangular vault, whose floor of masonry is kept constantly covered with a film of flowing water about four inches in depth. The air is forced between the water surface and iron plates surrounding the mouth-pieces of the inlet, the opening being about three inches wide, so that all the dust must touch the water and will be carried away by that outflow.

Some very light particles will not be retained by the water at first; but, by reason of the large cross section of the vault, the volume is sufficient to reduce the velocity of the air and permit the settling of the dust into the water by gravity beyond the mouth-pieces.

Two dust-collectors like this have been built in the mill referred to, underground, near the buildings, the top being covered with a grating to permit the escape of the air draught; the water used in the collector is the water of condensation from the steam engines, and its level is made constant by the height of the overflow. The vaults have a floor dimension fifty feet long and seventeen feet wide. The light dust is carried by the

overflowing stream into the river, but the flocks and tufts of flax are arrested by a movable grating in the discharge channel and are collected by the aid of a brush. The automatic action of this apparatus is secured by having a revolving cylinder carry movable gratings whose bars are driven by cams ; when the bars have passed through the water, they are drawn into the cylinder, and the dust remaining on the circumference of the latter is easily collected upon a suitable brush fixed close to the revolving cylinder.

DXXXVI.*

EXPERIENCES IN THE OPERATION OF RACK RAILWAYS.

BY ALBERT SCHNEIDER, HARZBURG, GERMANY.

When, in the year 1803, Richard Trevethick amazed the people of London with a road locomotive running through the streets of the city, and in the following year excited again their admiration by pulling, for the first time, a coal train up an incline in South Wales by means of a steam engine on wheels running on iron rails, he introduced at the same time an error into railroad construction which for a long time hindered the development of locomotive systems and which must be considered as one of the most peculiar features in the history of inventions.

The wheels of his engine, on the tread projecting over the rails, were provided with nails, the heads whereof were to take hold in the wood of the longitudinal track sills, it being supposed that otherwise wheels driven by steam, as they were, would slide on the rail and rotate on the spot, instead of executing a progressive motion.

This error became, and remained with astonishing persistency, a leading factor in all subsequently attempted constructions of locomotives.

The engineers of that time thought that the friction of the apparently smooth wheels on rails, also apparently smooth, was not sufficient for overcoming the opposing gravity force of heavy trains when ascending even moderate grades. So it occurred that Blenkinsop constructed in 1811 the first toothed, or rack bar, and built upon this system a short railroad near Leeds. His rack was connected with one of the outer rails; hence it could not give satisfactory results, and consequently was soon abandoned.

It was the merit of W. Blackett to deliver the community from the above-mentioned deeply rooted error, and to demonstrate, for the first time, the fact that the friction between wheel and rail is sufficient for effecting traction. Desirous of introducing the steam

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

engine into railroad service, he made in 1814 a simple practical experiment which proved the efficiency of adhesion friction and which infused new energy into the developments of locomotive constructions.

A few years after Blackett's experiment, George Stephenson built the first locomotive that was intended to produce tractive power by mere adhesion. The idea was at first ridiculed and denounced as a bold risk; but the perfect success of the locomotive soon turned the tide of public opinion, and Stephenson won for himself great popularity among his countrymen and well-deserved admiration from the whole technical world. His five "iron horses" hauled, in 1819, on the Hatton coal road, to the surprise of the people, trains with a speed of four English miles per hour.

It was, therefore, the adhesion of the driving wheels of the locomotive to the rails that worked this wonder, and this adhesion is simply the frictional resistance caused by the pressure of the wheels on the rails, which friction works against the tractive force manifested at the circumference of the wheels.

If the tractive force of the locomotive (*i.e.*, the power developed by the steam) is greater than the adhesion; or, reversed, if the friction between wheels and rails is smaller than the tractive force—then the wheels slide on the rails and revolve without moving the train forward. In other words, adhesion locomotives (whereof there are, at present, distributed over the whole globe, over 70,000 in operation) can only work when the friction of the drivers on the rails is greater than the sum of all resistances that work against the traction. The amount of this friction is measured by the weight resting on the driving axles multiplied with a certain coefficient to be determined by experience. This coefficient is subjected to very great fluctuations, and depends upon the condition of the surfaces of the rails. If they are perfectly clean and dry, the coefficient of friction is about $\frac{1}{5}$, and at average weather conditions can be assumed to be $\frac{1}{6}$ to $\frac{1}{7}$; when the rails are damp, in rain, snow, fog, or in tunnels, the coefficient may drop to $\frac{1}{12}$, and if the rails are greasy or iced, even to $\frac{1}{20}$. In order to increase as much as possible the useful friction, the locomotives have gradually been constructed heavier and heavier, weighing at present 15 tons, and in single cases even 19 tons per axle, which enormous weight was found to be necessary for complying with the constantly increasing demands for steeper grades; but, to work economically, the natural adhesion of even these very heavy locomotives is not sufficient to overcome

steep inclines, such as are frequently necessary on mountain railroads.

Therefore, in mountainous regions we have only a choice between two alternatives; either to imitate a plain on the mountains, viz., to lay railroad lines with such inclinations that the natural adhesion is sufficient for the advantageous operation of a common locomotive, or to construct a motor, the efficiency of which would not depend upon its own weight, and even would develop a greater adhesion than that derived from the weight, and, consequently, would have sufficient traction for ascending much steeper gradients than could be done with adhesion locomotives. Owing to the immense expenses involved in the first plan, a great deal of attention has in recent times been given to the second alternative. In other words, rack bar and cogwheel, abandoned years ago, have been taken up again, and, improved with the best appliances of the mechanical arts, have been made a great success in modern railroad engineering. We experience, therewith, the peculiar and rare case, where regress has proved to be progress.

The rack bar is, in a certain measure, the precursor of our normal, apparently smooth, track rail. I purposely say "apparently" smooth, because it is really a rack bar with an infinite series of small teethlets created by the pressure of the wheel on the rail at every point of contact, this being the true cause of the indispensable friction. But for these diminutive teethlets, which are on the wheel as well as on the rail, the points of contact would be infinitely smooth and the adhesion be equal to naught.

Thus, the rack bar, which in the infancy of railroading owed its invention to an error, has now risen to great mechanical importance, furnishing, as it does, the acknowledged safest and most economical means for moving railroad cars over steep inclines.

If we point with justifiable pride to the success we have achieved in climbing over the highest mountains with ordinary railroads, we must, at the same time, confess that this was only possible through the expenditure of enormous sums necessary for establishing with artificial means a but slightly inclined railroad bed on the rugged and precipitous topography of the mountains.

These means consisted in digging deep cuts, in throwing up high embankments, in building superb bridges, and, principally, in boring immense tunnels through the mountain masses that stood in the way, making therewith certain projects possible which at first seemed to be impossible.

The construction of the Semmering, Mount Cenis, St. Gothard, Arlberg, and Brenner railroads are telling proofs of the genius and the energy of the railroad engineers of our times and of the wonderful progress of the technical sciences, but closely attached to these triumphs is also the undeniable fact that the cost of such works is simply appalling.

The Semmering road, for instance, by a length of 25½ miles (= 41 km.), has cost over $11,000,000 (= 46,500,472 Mark), or per mile $434,315 (= 1,140,000 Mark per kilometre).

The great Gothard tunnel has a length of 8.7 miles (= 14 km.) and cost $10,851,000 (= 57,000,000 francs).

These enormous figures necessarily set people thinking and considering whether the *ordinary* adhesion road and our *ordinary* types of locomotives were the only admissible and indispensable means for mountain transit, or whether it was not possible to discover better and more economical means for accomplishing this purpose. The importance of this question grew more urgent, in the face of the constantly increasing and more and more pressing wants for railroad communications in mountainous regions. The thorough investigation of the subject led to the conclusion that the usual adhesion roads, which, indisputably, are the best medium for communication on the plain or on rolling ground, would in the mountains be too expensive for returning any profits to the invested capital, and that it would be necessary either to build such roads with steeper grades and work them with specially constructed motors, or to abandon the adhesion system entirely and substitute for the same a new and different principle. All endeavors to solve the problem, as first indicated, have completely failed and scarcely deserve a passing notice. In the second direction, however, viz., substituting for natural adhesion artificial means of traction, we have two rational solutions of the problem in the rope incline and in the rack system.

Rope inclines, where cars are raised by means of a wire rope and stationary engine, have been used extensively for short and very steep inclines, but never have found application for long distances or on through lines. For the latter cases it is the rack system alone that, according to our present experience, has been the best solution of the question of overcoming steep grades with railroads, and, therefore, has proved to be the most economical method of communication in the mountains.

It was half a century after Blenkinsop's first attempt of a rack

railroad, that the same, but almost forgotten, idea was readopted by Sylvester Marsh in America and, on his example, by Riggenbach in Europe; but their plans appeared, yet in the second half of this century, to our engineers so ridiculous and adventurous that both men, on either side of the ocean, had to struggle hard before they succeeded in putting their schemes into practical execution. It was not until 1869 that Marsh could demonstrate the correctness of his calculations by the then completed rack railway on Mt. Washington, New Hampshire, which ascends grades of 1 in 2.7; and it was only through the success of this enterprise that Riggenbach obtained in 1870 the concession for the construction of a railroad on the Rigi mountain, and succeeded in raising the necessary capital for the same. The Rigi road surpassed all expectations respecting the safety and punctuality of traffic, it increased the concourse of visitors at that renowned vista to never dreamed of proportions, and established a precedent that acted as a fruitful incitement for the planning and realizing of similar projects. A second cog-wheel road on the Rigi was completed in 1875, and the construction of many other roads, in rapid succession, was the natural consequence of the success of the rack system as demonstrated anew with each new railway.

The following table "A" gives a synopsis of all rack roads built on the Marsh or Riggenbach systems:

TABLE A.

No.	Name and Location.	Length.		Max. grade per cent.	Gauge.		Mode of operation, whether rack alone or rack and adhesion combined.
		Miles.	Km.		Feet.	Mm.	
1	Mount Washington, New Hampshire	3.29	5.3	37	4′ 8½″	1.435	Rack.
2	Vitznau, Rigi, Switzerland	4.35	7.	25	4′ 8½″	1.435	"
3	Ostermundingen, Switzerland	0.93	1.5	10	4′ 8½″	1.435	Rack and adhesion.
4	Kahlenberg, Austria	3.11	5.	11	4′ 8½″	1.435	Rack.
5	Rorschach, Heiden, Switzerland	3.42	5.5	9	4′ 8½″	1.435	"
6	Arth, Rigi, Switzerland	5.59	9.	21	4′ 8½″	1.435	"
7	Wasseralfingen, Germany	1.24	2.	7.8	3′ 3⅜″	1.000	Rack and adhesion
8	Rüti, Switzerland	0.31	0.5	10	4′ 8½″	1.435	" " "
9	Laufen, Switzerland	0.19	0.3	5	4′ 8½″	1.435	" " "
10	Friedrichshegen, Germany	1.55	2.5	10	3′ 3⅜″	1.000	" " "
11	Green Mt., Mount Desert, Maine	3.73	6.	25	4′ 8½″	1.435	Rack.
12	Petropolis, Brazil	4.35	7.	15	3′ 3⅜″	1.000	"
13	Corcovado, Brazil	2.17	3.5	30	3′ 3⅜″	1.000	"
14	Drachenfels, Germany	1.24	2.	20	3′ 3⅜″	1.000	"
15	Rüdesheim, Germany	1.49	2 4	20	3′ 3⅜″	1.000	"
16	Degerloch, Germany	1.24	2.	17.2	3′ 3⅜″	1.000	"
17	Zakarotz, Hungary	3.42	5.5	8	3′ 3⅜″	1.000	Rack and adhesion.
18	Assmannshausen, Germany	0.93	1.5	20	3′ 3⅜″	1.000	Rack.
19	Naples, Italy	0.50	0.8	7	3′ 3⅜″	1.000	"
20	Gaisberg, Austria	3.42	5.5	25	3′ 3⅜″	1.000	"
21	Langers, France	0.93	1.5	17	3′ 3⅜″	1.000	Rack and adhesion.
22	Sumatra, Asia	18.64	30.	12	3′ 3⅜″	1.000	" " "
23	Bühnig, Switzerland	9.94	16.	12	3′ 3⅜″	1.000	" " "
24	Höllenthal, Black Forest, Germany	21.75	35.	5.3	4′ 8½″	1.435	" " "
25	Petersberg, Germany	0.81	1.3	26	3′ 3⅜″	1.000	Rack.
26	Ienbach, Germany	2.05	3.3	16	3′ 3⅜″	1.000	"

All of these roads have the same construction. The rack rail, laid in the centre of the track, is formed of two upright angle or channel irons, between which the teeth, in shape of round or trapezoidal bars, are riveted or screwed. The rack rail resembles, therefore, in general form an iron ladder, from which the term "ladder system" has been derived to denominate the Marsh rack as well as all subsequently modified types of the same system.

The cogwheel of the locomotive, of course, corresponds with the rack, the teeth of the former working into the teeth of the latter and receiving a direct and absolutely firm hold.

The ladder rail is generally manufactured in sections of 9 feet 10 inches (= 3 metres) length, weighing 113½ to 121 lbs. (= 51.6 to 55 kilo), which is equal to 11½ to 12½ lbs. per foot (= 17.2 to 18.3 kilo per metre). The Hoellenthal rack, however, is heavier, weighing per section 222 lbs. (= 101 kilo).

With respect to the shape of the teeth, which evidently is of high importance in the construction of a rack, Mr. Riggenbach has solved the problem, theoretically and practically, by adopting evolute gearing, which combines the two principal conditions of a well-constructed gearing; viz., simplicity of the form of the teeth, and the admissibility of an increasing or diminishing distance between the pitch lines of the wheel and the rack bar.

In spite of the many advantages which Marsh's and Riggenbach's inventions offered to railroad engineering, their systems have been used, until recently, only for short distances on roads with special travel, and its practicability for through lines with heavy and varying traffic has yet to be proved.

It was reserved for Roman Abt, of Luzern, to invent an entirely new type of rack bar and a new locomotive, which accomplishes thoroughly the hitherto rarely attempted and imperfectly executed combination of the rack and adhesion systems.

The first application of Abt's invention was made on a railway from Blankenburg to Tanne in the Harz mountains, and the first combination locomotive ever built that worked rationally is still running on this line. It was a most happy thought to adopt for the Harz railroad the combination system, meaning a profile in which light grades alternate with steep grades, the former being worked by mere adhesion, the latter by adhesion assisted by rack and cog wheel, or, if too steep for adhesion, by rack gearing alone. This combination method of building and operating a railroad, which solved a problem that had baffled for a long time the

engineers of that part of Germany, gave at last to the dwellers in the Harz mountains the long looked and hoped for railroad communication with the outer world.

Topographical conditions similar to those existing in the Harz mountains are very frequent; hence the splendid success of the Harz road has already borne plentiful fruit, manifested by the construction of many similar railroads in all parts of the earth.

THE "ABT" RACK RAIL.

Abt's rack rail is not ladder shaped, like Riggenbach's, but it is multipartite with staggered teeth. It consists of several rectangular bars (lamellae) resting side by side on specially constructed chairs, which are attached to the iron cross-ties of the track. The number and size of the single bars depends upon the tooth pressure, which in itself is a consequence of the train weight, the velocity of the train, and of the inclination of the road.

It is not my purpose at this place to enter into a detailed description of the Abt rack, as it has been described fully and repeatedly in almost all technical periodicals of Europe and America. Of the latter I merely mention the *Railroad and Engineering Journal*, by M. N. Forney, February, 1890. The advantages of the Abt rail, as compared with the ladder rack, are manifold, and have fully been demonstrated since its introduction in 1885.

The following are some notable points:

1. The Abt rail forms *one complete and continuous* rack bar, while Marsh's rail is composed of a series of *separate and loosely jointed pieces*. These joints are the weak points of the ladder rail. All motions, in consequence of "creeping" or of the contraction and expansion of the metal, are concentrated at the joints, forming weak points and causing enough inaccuracy in the pitch division to make the working of the gear wheel disagreeably impactlike. The manner in which the ladder rail necessarily must be constructed, makes it impossible to eliminate those imperfections or even to distribute them in any way. The manner of constructing the Abt rail, on the other hand, obviates all such difficulties by placing at least one or two full bars, according to the rail being bipartite or tripartite, directly opposite the joint of two adjoining bars. Hence, unlike the ladder rack, there are no through joints in the Abt rack, which, consequently, forms an uninterrupted rail, *equally strong* and *equally accurate* in *its whole length*. Considering that each bar is only 8 feet 8 inches (= 2.650 metres) long, and that

IMPERIAL AUSTRIAN RAILWAYS.

Wear of teeth of the locomotives of the Eisenerz-Vordernberg R.R., after having travelled the first 10,000 kilometres = 6,2[illegible] miles, from April 1, 1891, to April 1, 1892.

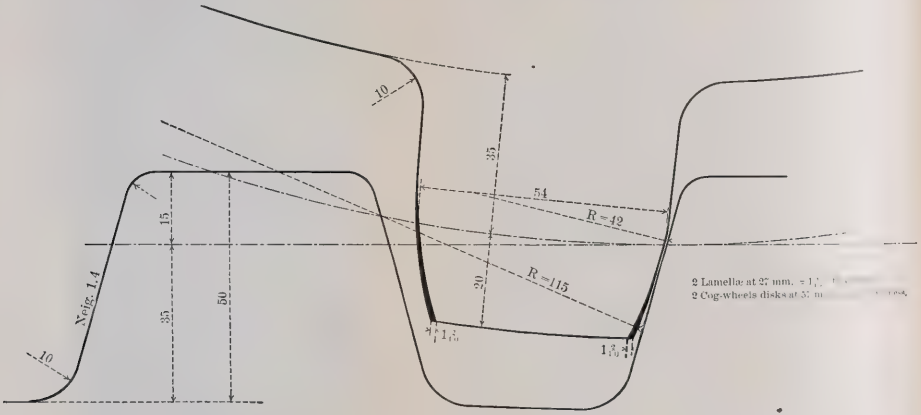


FIG. 278.

GAUGE SHOWING THE WEAR

OF THE COUPLED COG-WHEEL OF THE LOCOMOTIVE "TANNE," MARCH 1, 1893.

In operation seven years.

Original thickness of tooth = 56 mm. = $2\frac{3}{16}$"
Present thickness of tooth = 47 mm. = $1\frac{27}{32}$"

Wear per year = 1.28 mm. = $\frac{3}{64}$"

Wear at the pitch line :
a. On each side of the tooth = 4.5 mm. = $\frac{11}{64}$"
b. Total wear = 9 mm. = $\frac{11}{32}$"
c. Admissible wear on each side = 8 mm. = $\frac{5}{16}$"
d. Admissible total wear = 16 mm. = $\frac{5}{8}$"

Distance run :
111,723 km. = 68,380 miles.

Wear per 10,000 km.,
or 6,200 miles = 0.805 mm. = $\frac{1}{32}$"

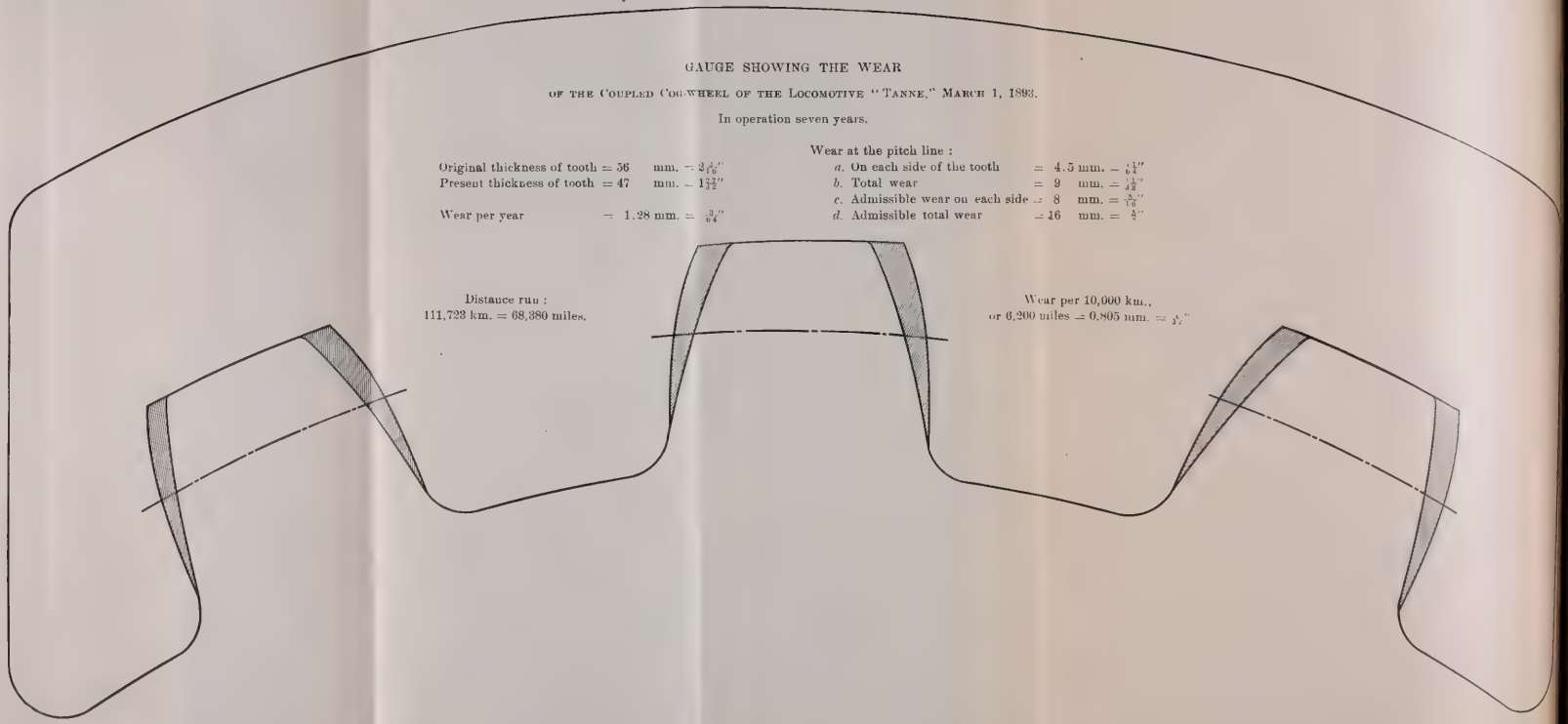


Fig. 277.

GAUGE SHOWING THE WEAR

OF THE COUPLED COG-WHEEL OF THE LOCOMOTIVE "TANNE," MARCH 1, 1893.

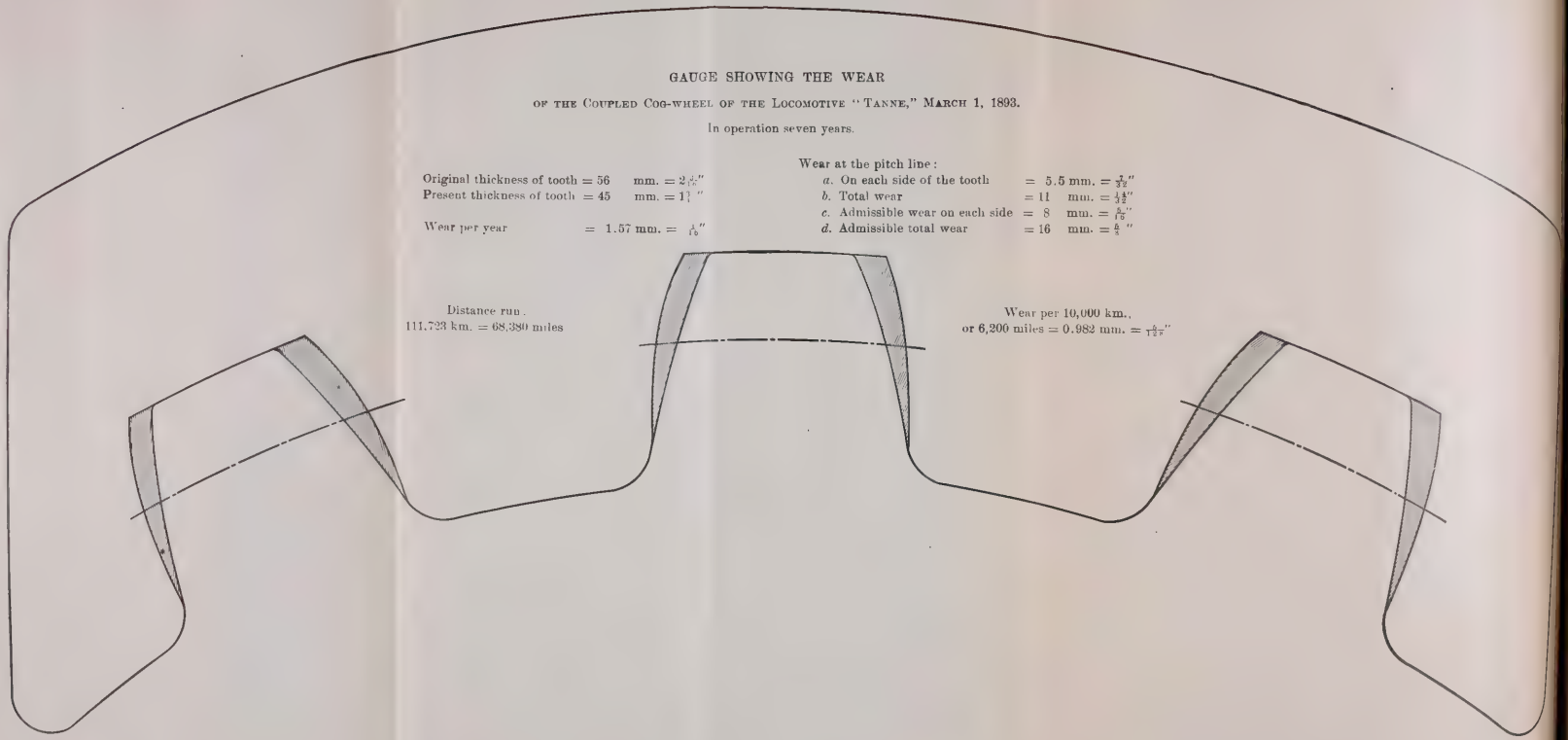
In operation seven years.

Original thickness of tooth = 56 mm. = $2\frac{13}{16}$"
Present thickness of tooth = 45 mm. = $1\frac{7}{8}$"

Wear per year = 1.57 mm. = $\frac{1}{16}$"

Wear at the pitch line:

a. On each side of the tooth = 5.5 mm. = $\frac{7}{32}$"
b. Total wear = 11 mm. = $\frac{7}{16}$"
c. Admissible wear on each side = 8 mm. = $\frac{5}{16}$"
d. Admissible total wear = 16 mm. = $\frac{5}{8}$"



it is firmly held in its centre, it can readily be seen that the dilation of only 4 feet 4 inches must be distributed over all the teeth of the whole bar, which makes the single pitch difference too small to be of any practical consequence. While the motion on Riggenbach's ladder rack is boundwise, the wheel jumping from one round of the ladder to the other, that of Abt's rack is soft and continuous, like the motion of a nut on a screw.

2. The Abt rack is admirably adapted for the construction of track curves, because all rack bars are alike and each single bar is interchangeable, and can be used in tangents as well as in any kind of curve.

The ladder rack, on the other side, requires specially constructed segments, not only for every different degree curve but also for right and left curves of the same degree, and even then the teeth of the wheel touch those of the rack only at one point.

To diminish this imperfection as much as possible, the Riggenbach rack requires curves of large radii, while the Abt rack admits as sharp curves as are practical in any railroad service.

The contact of the teeth in the Abt gear is almost perfect when new, but becomes absolutely perfect after being in use some time, because the teeth of the bar wear themselves into shape to correspond to the slightly oblique position of the wheel when passing around curves. After a perfect contact has been reached, the wear of the rack bar teeth practically stops, and that of the cogs of the wheel is *very small.*

3. With the present traffic on the Harz railway, according to my observation and calculation, the rack teeth will wear $\frac{1}{25}$ of an inch (= 1 mm.) in 150 years, while the cog-wheels will last twelve years before being worn out. On the Riggenbach system, as experience has taught, the wheels must be replaced every two years if they work under normal conditions.

Figs. 277 and 278 show the wear of a tooth of the locomotive "Tanne" after having been in operation for eight years; Fig. 279 shows the wear of a cog of an Eisenerz-Vordernberg locomotive after one year's use. It is, of course, evident that the wear in the first years, before the teeth have adapted themselves to the rack teeth, is greater than in the subsequent years, hence the wear in the first eight years must necessarily be more than half the admissible wear.

4. The strength of the Abt rail is practically unlimited and can easily be varied according to requirements, by simply increasing

the thickness of the single bars or by adding another line of bars. The ladder rack, on the other hand, has already reached about the limit of its practical strength, because here an increase in strength means also an increase in pitch division, which would lead to new complications in the construction of the locomotive. We shall see that the Höllenthal rack, which is the heaviest and strongest ladder rail yet constructed, would not be capable of resisting the same pressure as the Harz rack does, which is by no means the strongest Abt rail that could be constructed.

5. Owing to the staggered tooth system, making it possible for several teeth to work simultaneously, and leaving no interval between the contact of two successive teeth, the speed of the locomotive on the Abt rail can be much greater than on the ladder rail. If it were economical for a locomotive to run with a speed of 15 or 16 miles an hour up a 6% grade, this velocity could unhesitatingly be adopted for all trains without causing shocks or making much noise, while on the ladder rail the motion at a five-mile speed resembles the action of a trip-hammer.

6. The cost of maintaining the Abt rail is equal to naught, hence the Board of Trustees of the Harz railway has refrained from providing a reserve fund for the eventual renewal of the rail. Considering our exceedingly strict laws and regulations, this circumstance is in itself a splendid testimony for the perpetual duration of this rack.

The following table B gives a list of a number of Abt railroads in operation, with the principal data in regard to lengths, grades, etc.

The profiles of some of the roads named in the table are shown on Figs. 280 to 290, the rack rail types on Fig. 291, and the locomotive types on Figs. 292 to 295.

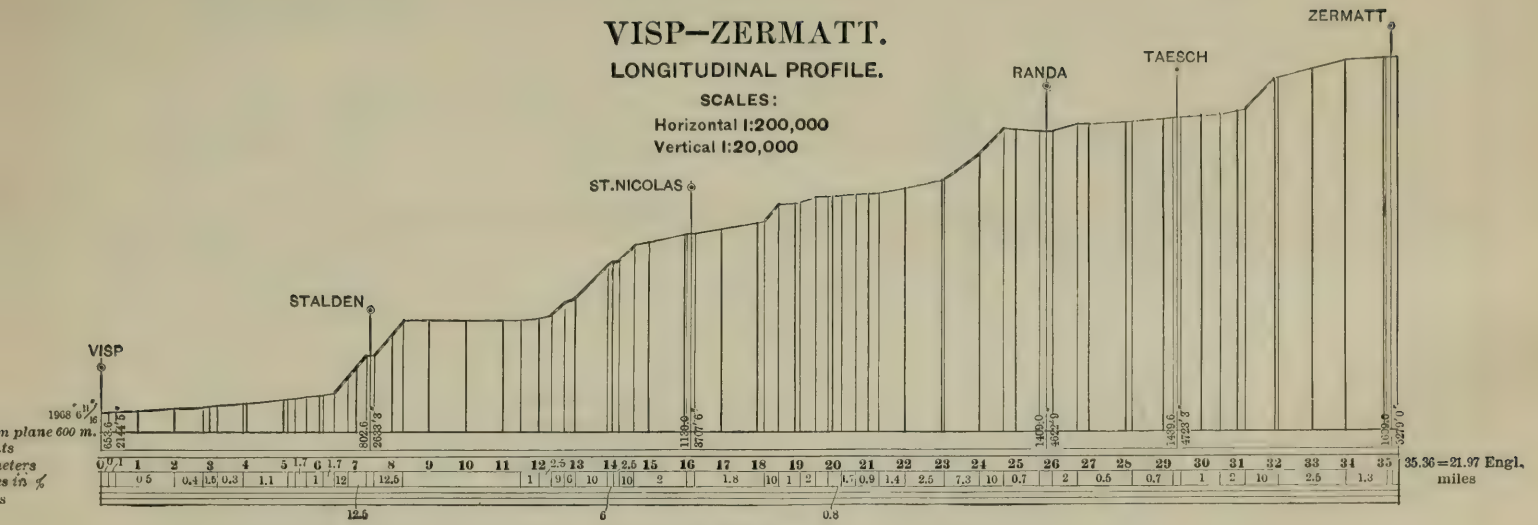

VISP—ZERMATT.
LONGITUDINAL PROFILE.
SCALES:
Horizontal 1:200,000
Vertical 1:20,000
VISP
STALDEN
ST.NICOLAS
RANDA
TAESCH
ZERMATT
35.36=21.97 Engl. miles

FIG. 280.

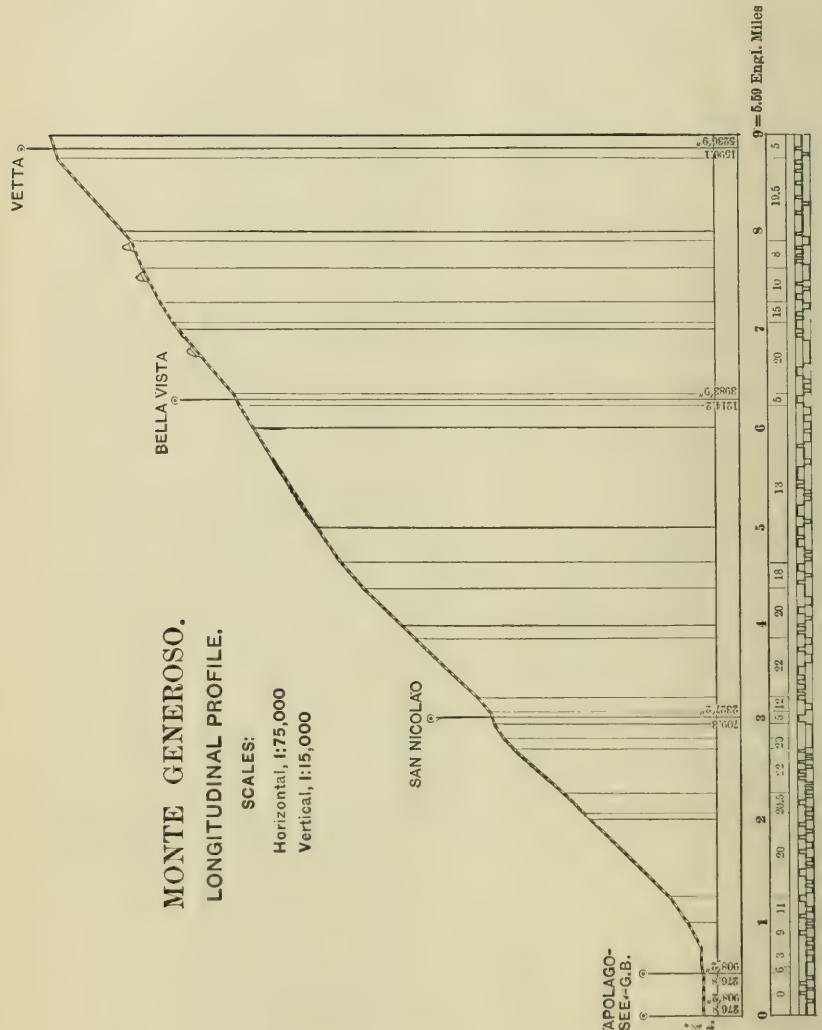

MONTE GENEROSO.
LONGITUDINAL PROFILE.
SCALES:
Horizontal, 1:75,000
Vertical, 1:15,000
VETTA
BELLA VISTA
SAN NICOLAO
CAPOLAGO-SEE-G.B.
Datum plane 280 m.
Heights
Kilometers
Grades in %
Curves
9=5.59 Engl. Miles

FIG. 281.

EISENERZ–VORDERNBERG

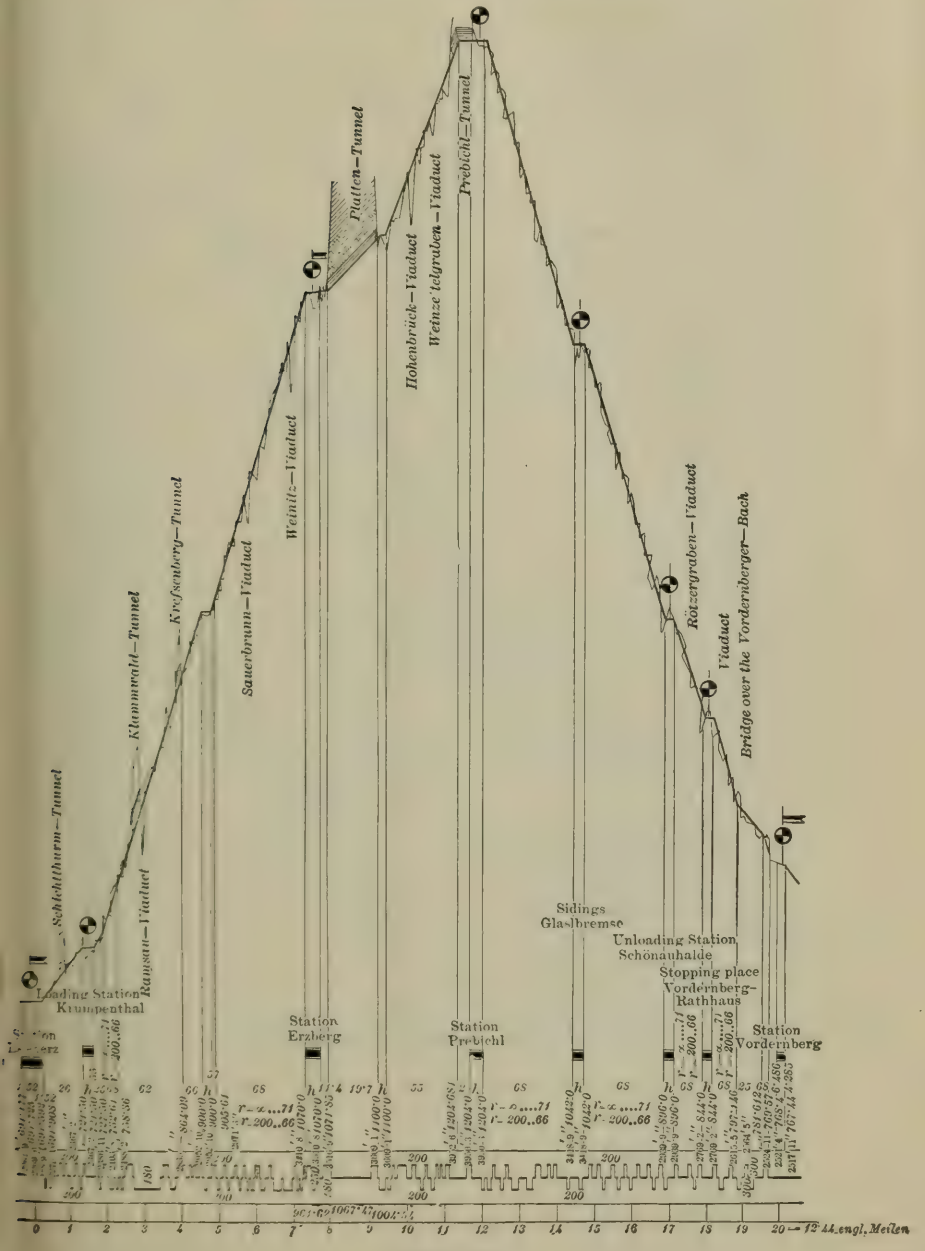


FIG. 282.

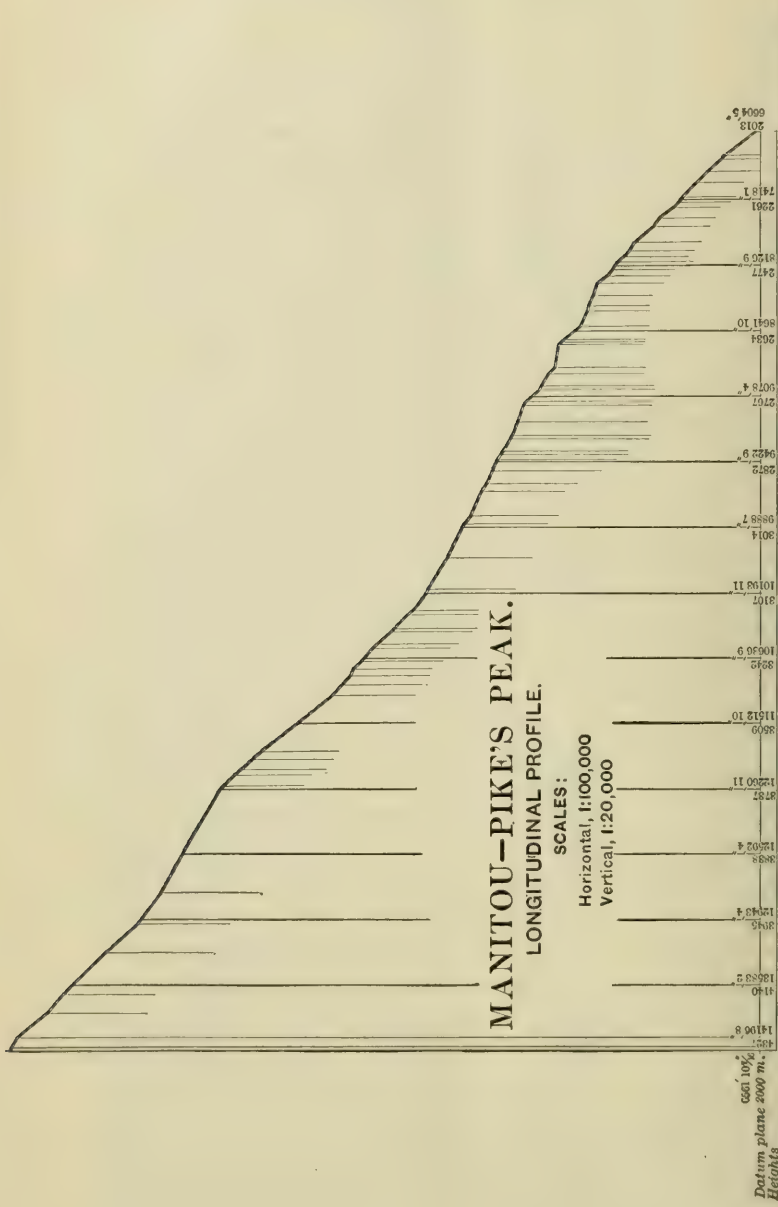

MANITOU—PIKE'S PEAK.
LONGITUDINAL PROFILE.
SCALES:
Horizontal, 1:100,000
Vertical, 1:20,000
14 = 6.70 Engl. Miles
Datum plane 2000 m.
Heights
Kilometers
Grades in %

Fig. 288.

DIACOPHTO—KALAVRYTA.

LONGITUDINAL PROFILE.

SCALES:
Horizontal, 1:150,000
Vertical, 1:15,000

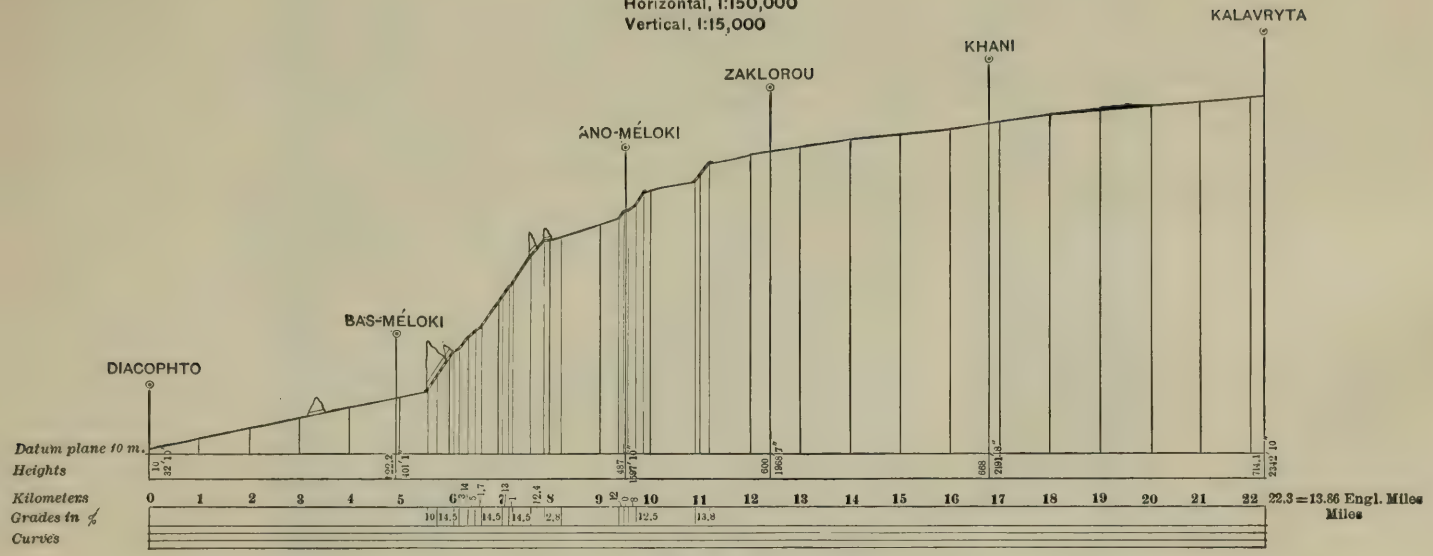


FIG. 284.

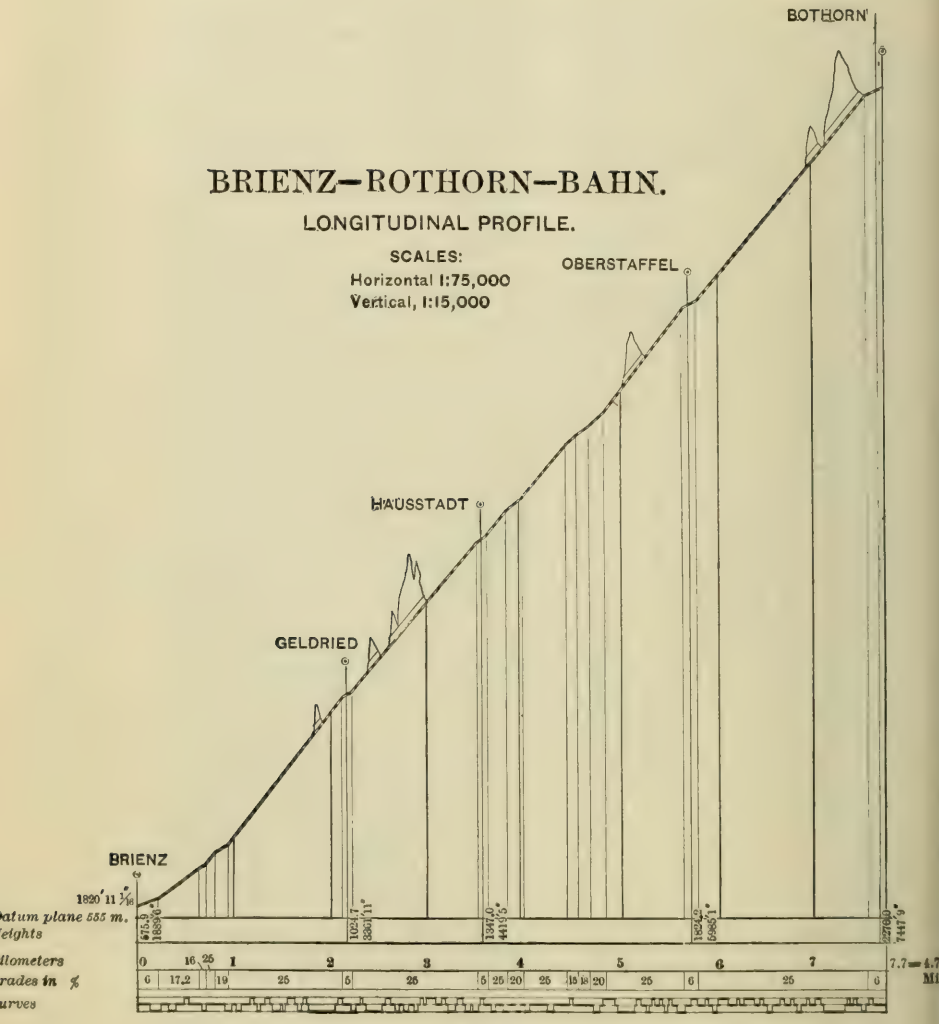

BOTHORN
BRIENZ—ROTHORN—BAHN.
LONGITUDINAL PROFILE.
SCALES:
Horizontal 1:75,000
Vertical, 1:15,000
OBERSTAFFEL
HAUSSTADT
GELDRIED
BRIENZ
1820' 11 1/16"
atum plane 555 m.
eights
675.9
1889.6
1024.7
3361' 11"
1346.0
4415' 6"
1824.9
6985' 1"
227660
7447' 6"
lometers
0 16 25 1 2 3 4 5 6 7
7.7 = 4.78 ml
rades in %
6 17.2 19 25 5 25 5 25 20 25 15 18 20 25 6 25 6
urves
Mile

FIG. 285.

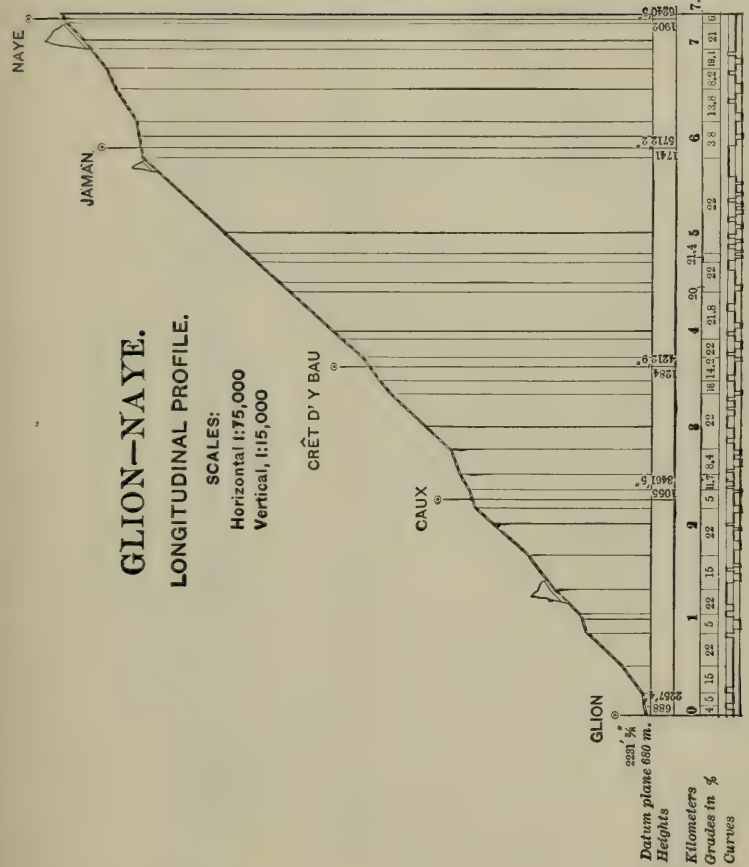

GLION—NAYE.
LONGITUDINAL PROFILE.
SCALES:
Horizontal 1:75,000
Vertical, 1:15,000
NAYE
JAMAN
CRÊT D' Y BAU
CAUX
GLION
7.25 = 4.51 Engl. Miles
Datum plane 680 m.
Heights
Kilometers
Grades in %
Curves

Fig. 286.

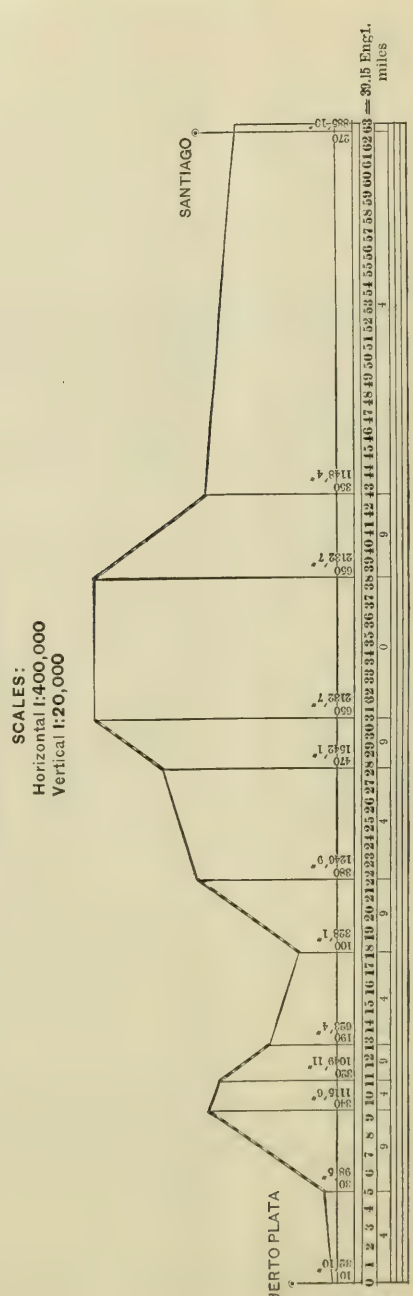

CENTRAL–DOMINICAIN.
LONGITUDINAL PROFILE.
SCALES:
Horizontal 1:400,000
Vertical 1:20,000
PUERTO PLATA
SANTIAGO
= 39,15 Engl. miles
Sea Level Heights
Kilometers
Grade in ‰
Curves

FIG. 287.

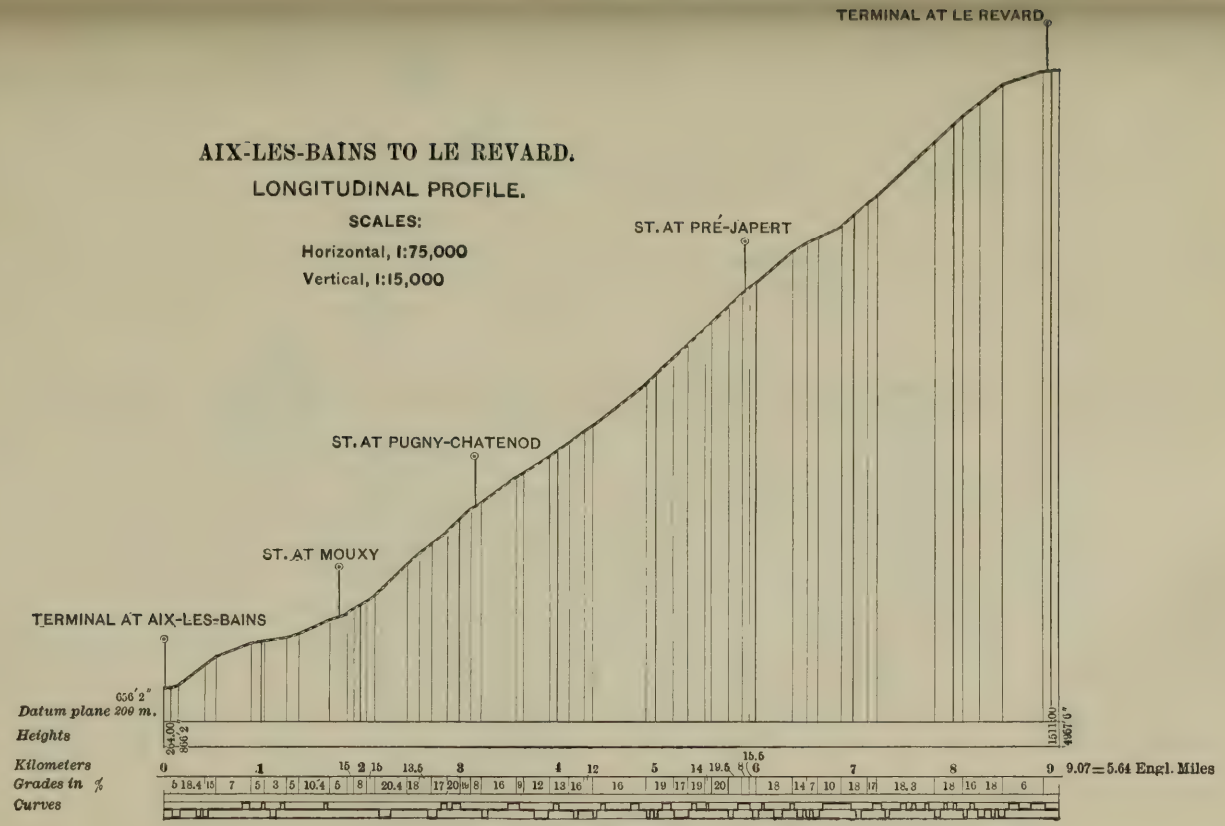
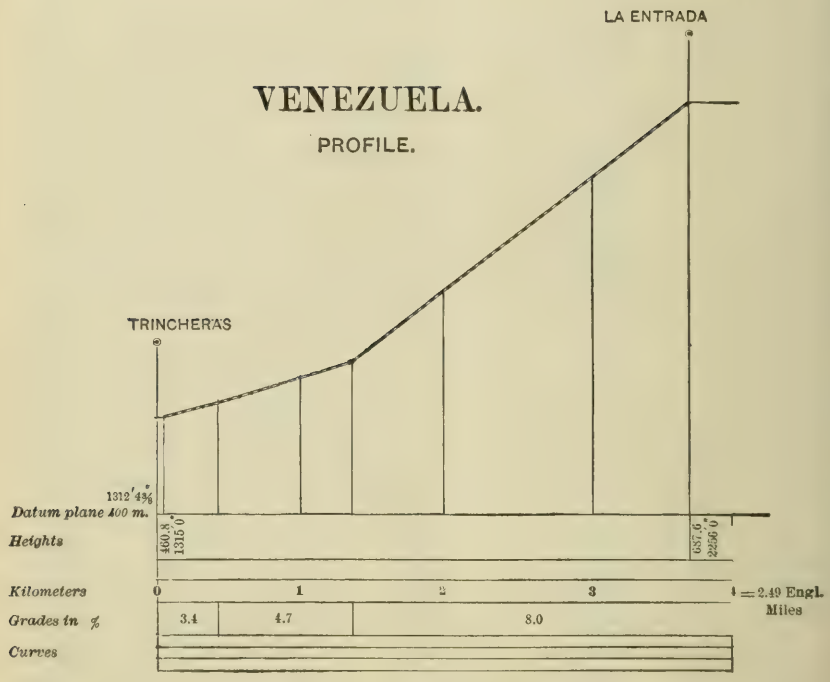

AIX-LES-BAINS TO LE REVARD.
LONGITUDINAL PROFILE.
SCALES:
Horizontal, 1:75,000
Vertical, 1:15,000
TERMINAL AT LE REVARD
ST. AT PRÉ-JAPERT
ST. AT PUGNY-CHATENOD
ST. AT MOUXY
TERMINAL AT AIX-LES-BAINS
656'2"
Datum plane 200 m.
Heights
Kilometers
Grades in %
Curves
9.07=5.64 Engl. Miles

FIG. 288.

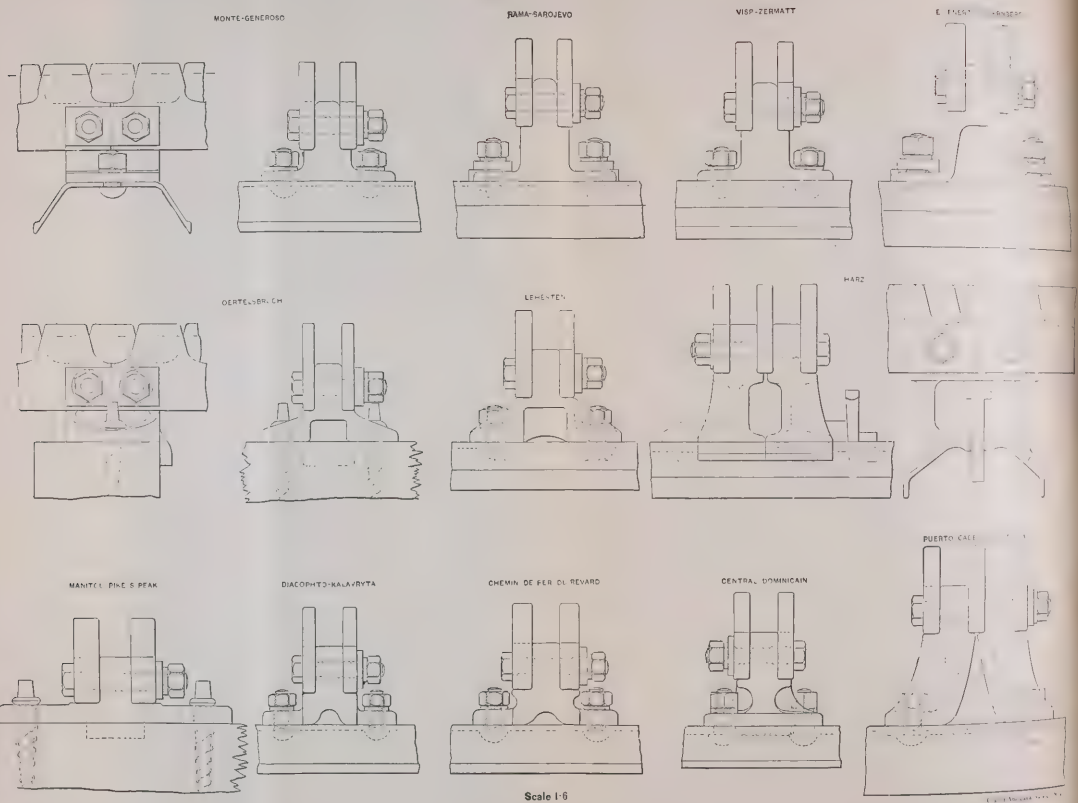


SCALES:
Horizontal, 1:25,000
Vertical, 1:2,500

FIG. 289.

FIG. 291.

RACK-PEDESTALS



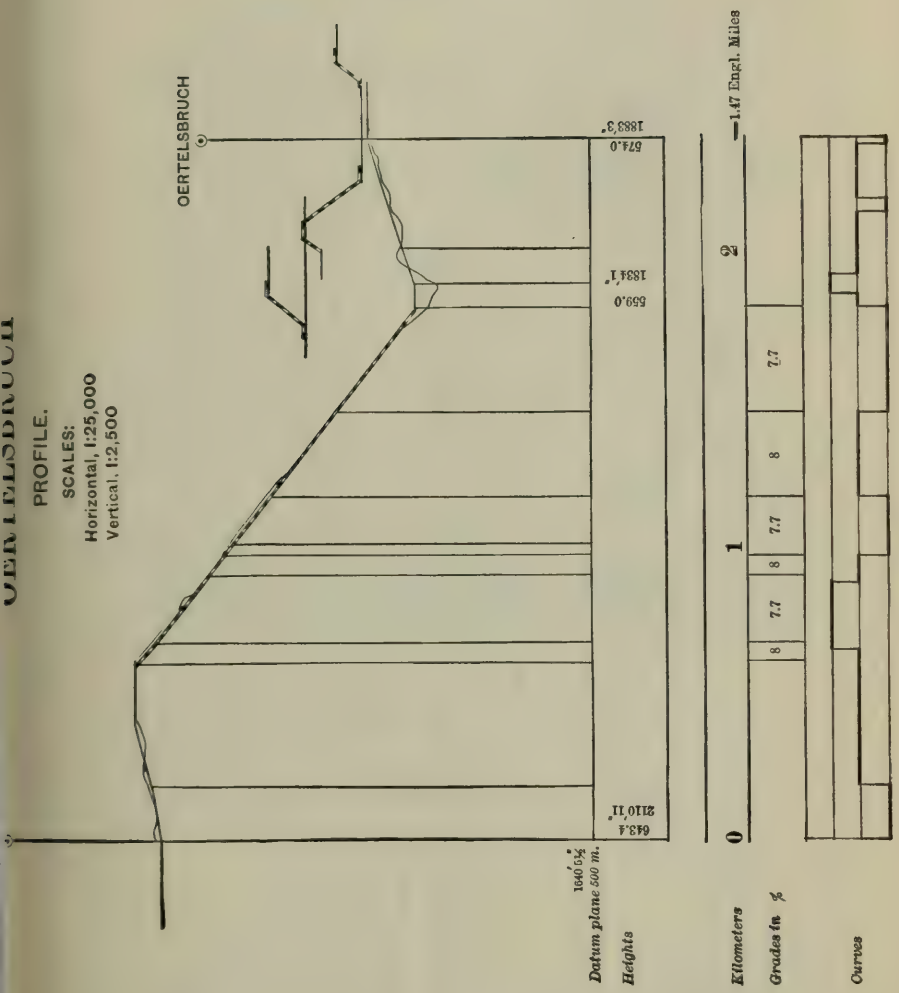

OERTELSBRUCH
PROFILE.
SCALES:
Horizontal, 1:25,000
Vertical, 1:2,500
OERTELSBRUCH
1883.3'
574.0
1834.1'
559.0
643.4
2110.11'
1640.5'
Datum plane 500 m.
Heights
0
1
2
1.47 Engl. Miles
Kilometers
Grades in %
8
7.7
8
7.7
8
7.7
Curves

FIG. 290.

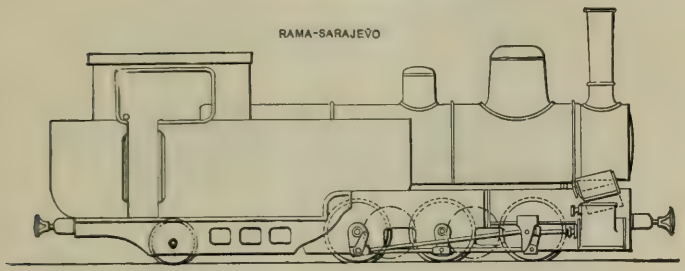
TABLE B.

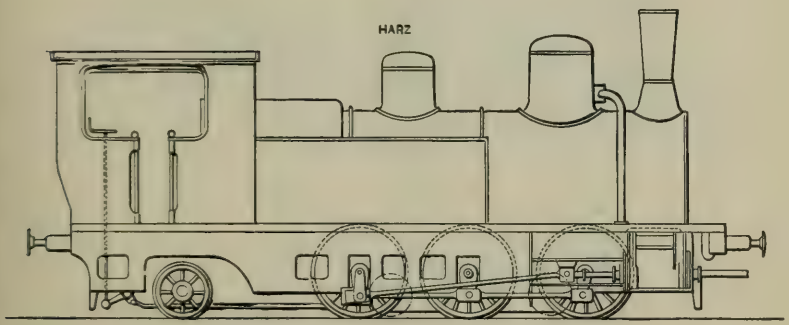
Rack Railways, Abt System.

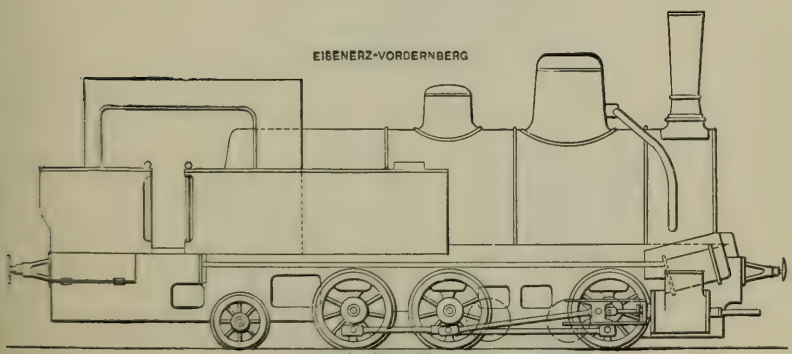
No.	Name and Location.	Gauge.		Length.				Max. Grade. Per cent. On.		Sharpest Curves.				Locomotives.						Train Weight, tons.	Mode of Operating.
				Rackrail.		Total.				Adhesion.		Rackrail.		Construction							
		Feet.	Mm.	Miles.	Km.	Miles.	Km.	Adhesion.	Rackrail.	Degree Curves.	Rad. Met.	Degree Curves.	Rad. Met.	Rack wheel.	Combination Rack and Adhesion.	Number.	When Built.	Weight, tons.	Tractive Power, tons.		
1	Harz Railway, Brunswick, Germany	4′ 8½″	1435	4.66	7.5	18.95	30.5	2½	6	9° 45′	180	8° 45′	200	....	R. & A.	5	1884-5	61	13	148	Pushing.
2	Lehesten, Thueringia, Germany	1′ 8½″	1435	0.81	1.3	1.68	2.7	3½	8	11° 30′	150	11° 30′	150	....	R. & A.	1	1885	25	6½	55	"
3	Oertelsbruch " "	2′ 3½″	690	0.43	0.7	3.11	5	5	13½	51°	35	17° 30′	100	....	R. & A.	2	1885	6½	2½	8	"
4	Puerto Cabello, Valenzia, Venezuela, S. A.	3′ 6″	1067	2.36	3.8	2.36	3.8	....	8	.....	.....	14°	125	R.	.....	3	1886	46	10	66	
5	Visp, Zermatt, Switzerland	3′ 3⅜″	1000	4.66	7.5	2.17	3.5	2.8	12½	22°	80	17° 30′	100	....	R. & A.	5	1889-90	32	10	50	Pulling.
6	Mt. Generoso, "	2′ 7½″	800	5.59	9	5.59	9	....	22	.....	.....	29° 30′	60	R.	.....	6	1889-90	16½	6	11	Pushing.
7	Rama, Sarajewo, Bosnia, Austria	2′ 6″	760	11.12	19.5	42.25	68	1½	6	14°	125	14°	125	....	R. & A.	8	1890	33	8	82½	Pulling.
8	Eisenerz, Vordernberg, Styria, Austria	4′ 8½″	1435	9.01	14.5	13.05	21	2½	7.1	11° 30′	150	9° 45′	180	....	R. & A.	12	1890	61	13	132	Pushing.
9	Manitou, Pike's Peak, Colorado	4′ 8½″	1435	9.32	15	8.80	14.2	....	25	.....	.....	16°	109	R.	.....	4	1890-2	25	12	20	"
10	Transandino, Chile, S. A	3′ 3⅜″	1000	17.40	28	31.07	50	2½	8	15° 15′	115	8° 45′	200	....	R. & A.	6	1890-1	46	9	66	"
11	Diakophto, Kalavryta, Greece	2′ 5½″	750	2.24	3.6	14.29	23	3½	14½	61°	30	35° 30′	50	....	R. & A.	3	1890-1	17½	5½	17½	Pulling.
12	Rothhorn, Switzerland	2′ 7½″	800	4.66	7.5	4.66	7.5	....	25	.....	.....	29° 30′	60	R.	.....	4	1891	18½	8	10	Pushing.
13	Glion, Naye, "	2′ 7½″	800	4.66	7.5	4.66	7.5	....	22	.....	.....	22°	80	R.	.....	6	1891	18½	8	11	"
14	S. Domingo, West Indies	2′ 6½″	765	3.98	6.4	22.37	36	4	9	35° 30′	50	17° 30′	100	....	R. & A.	4	1891	27½	8	55	Pulling.
15	Mt. Saléve, Savoy (electr.)	3′ 3⅜″	1000	5.59	9	5.59	9	....	25	.....	.....	51°	35	R.	.....	14	1891-2	7½	3	11	Pushing.
16	Wami, Toge, Japan	3′ 6″	1067	5.28	8.5	12.43	20	2½	6.7	.....	.....	6° 40′	260	..	R. & A.	4	1891-2	39½	11	110	"
17	Aix-les-Bains, Revard, Savoy	3′ 3⅜″	1000	5.72	9.2	5.72	9.2	....	21	.....	.....	23° 30′	75	R.	.....	8	1891-2	20	8	11	"
18	Montserrat, Spain	3′ 3⅜″	1000	4.97	8	4.97	8	....	15	.....	.....	22°	80	R.	.....	5	1891-2	18½	8	10	"
19	Schafberg, Austria	3′ 3⅜″	1000	3.73	6	3.73	6	....	25½	.....	.....	17° 30′	100	R.	.....	3	1892-3	20	8	22	"

FIG. 292.

RACK-RAIL LOCOMOTIVES



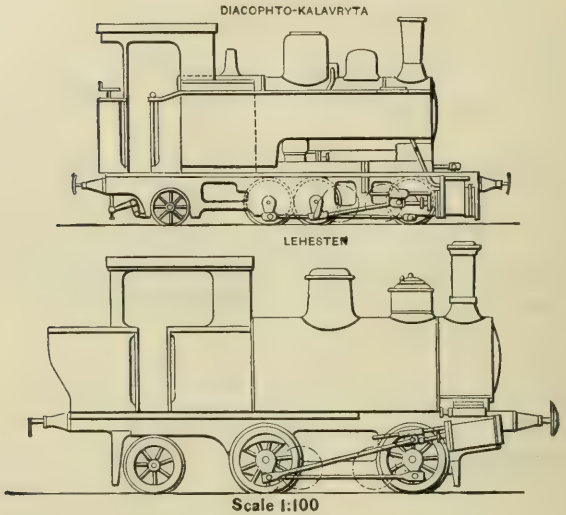




Scale 1:100

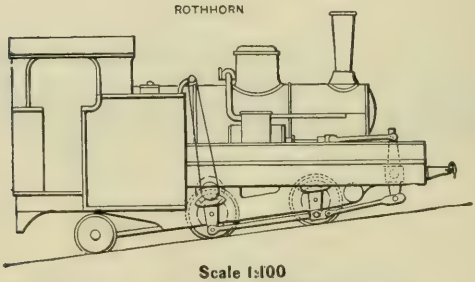
FIG. 293.

RACK-RAIL LOCOMOTIVES



Scale 1:100

PLATE 18.



Scale 1:100

RACK-RAIL LOCOMOTIVES

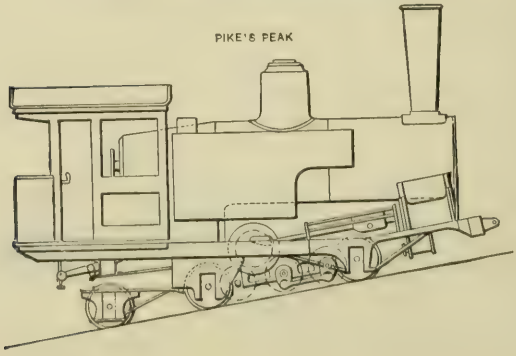


FIG. 294.

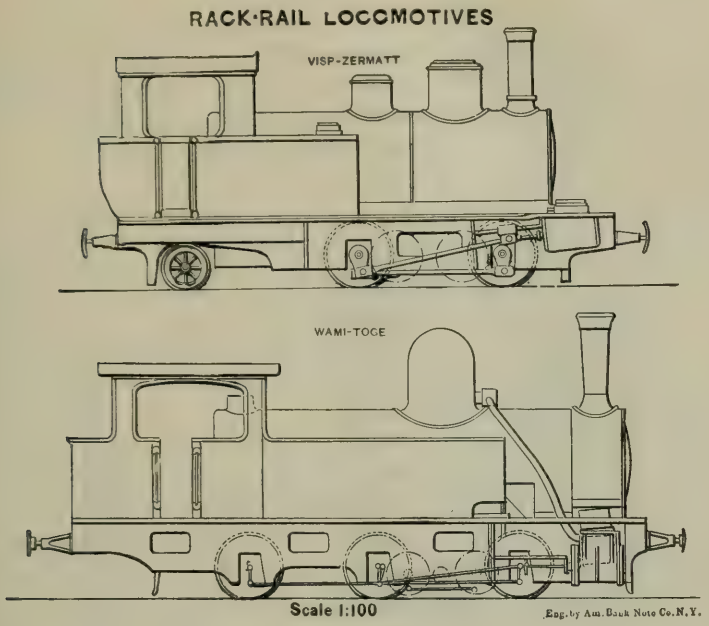
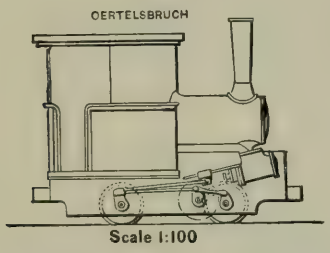
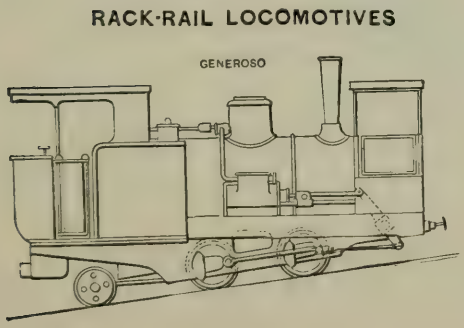


FIG. 295.





THE ABT LOCOMOTIVE.

The engine as used on the Harz railway is a tender locomotive with three coupled axles; it has an outside frame after the Hall system, outside adhesion cylinders and outside valve gear.

All three axles are in front of the fire-box and have a fixed wheel-base of 10 feet (= 3.05m.).

The diameter of the wheels is 4 feet 1 inch (= 1.25m.) and the weight on each axle, when in service, is 16 tons.

The frame, projecting at the rear end, is supported by a movable " Bissel " axle which bears a load of 13 tons.

The heating surface of the firebox is 89.4 square feet (= 8.3 sq. m.), that of the boiler tubes 1374 square feet (= 127.7 sq. m.), total 1464 square feet (= 136.04 sq. m.).

A separate frame, resting on two of the adhesion axles, supports the two coupled cogwheel axles. Owing to this arrangement the cogwheels are free from the oscillations which the main carrying springs transmit to the locomotive, and consequently the teeth of the wheels remain always in the same relative position to the teeth of the rack-bar. This construction is a great progress over former combination locomotives, where invariably the gear-wheels were fixed to the adhesion engine and where it was, therefore, necessary that the diameters of the adhesion drivers and those of the cogwheels should always have precisely the same relative proportions. The steam chests of the rackwheel cylinders are secured to the main frame, and the total rackwheel mechanism is located under the boiler.

The locomotive is provided with the following brakes:

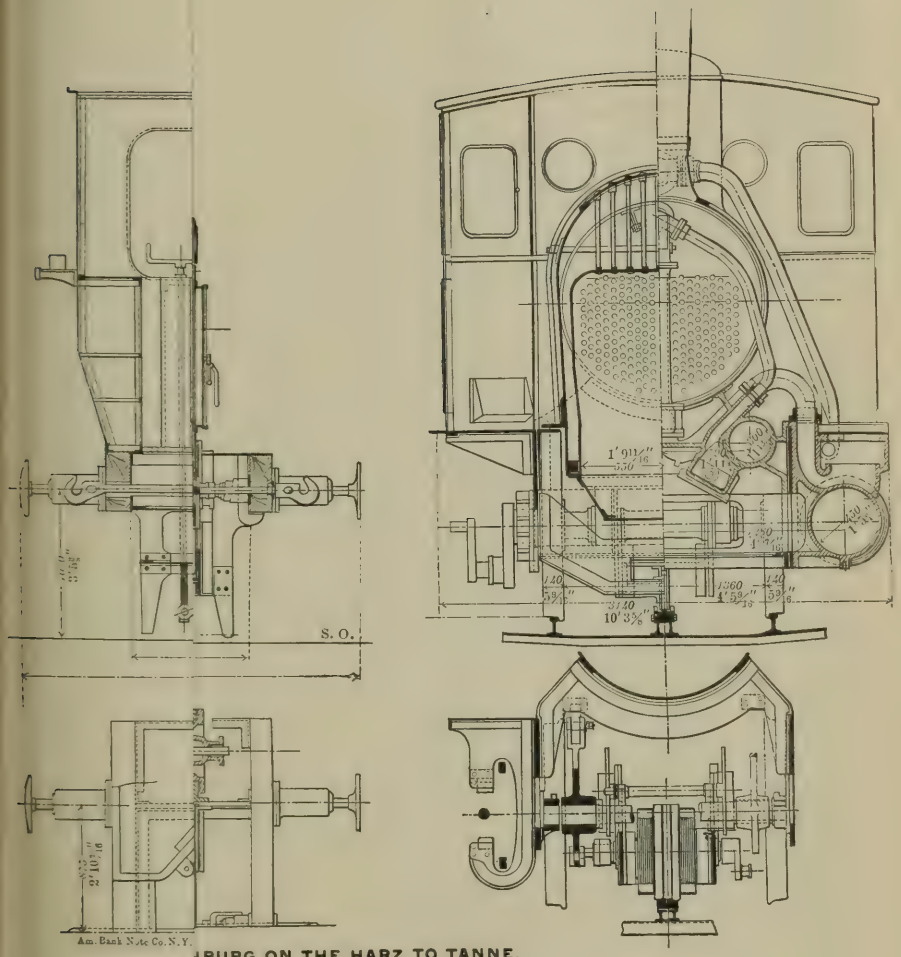
a. Two separate air brakes, one for the adhesion, the other for the rack engine. The air is sucked in from outside through a valve in the steam exhaust pipe, and the outlet of the air is regulated by two screw valves operated from the engineer's stand.

b. Each cog wheel is provided with two fluted brake disks against which corresponding brake shoes are pressed by means of a brake spindle located near the fireman's place.

c. Two ordinary screw brakes on the adhesion drivers, which are principally used in the shifting business and for stopping trains at the stations.

The locomotive, as will be noticed, consists of two independent engines, one for the adhesion service and one for the rack service, and it works most economically if each of these engines can, at the

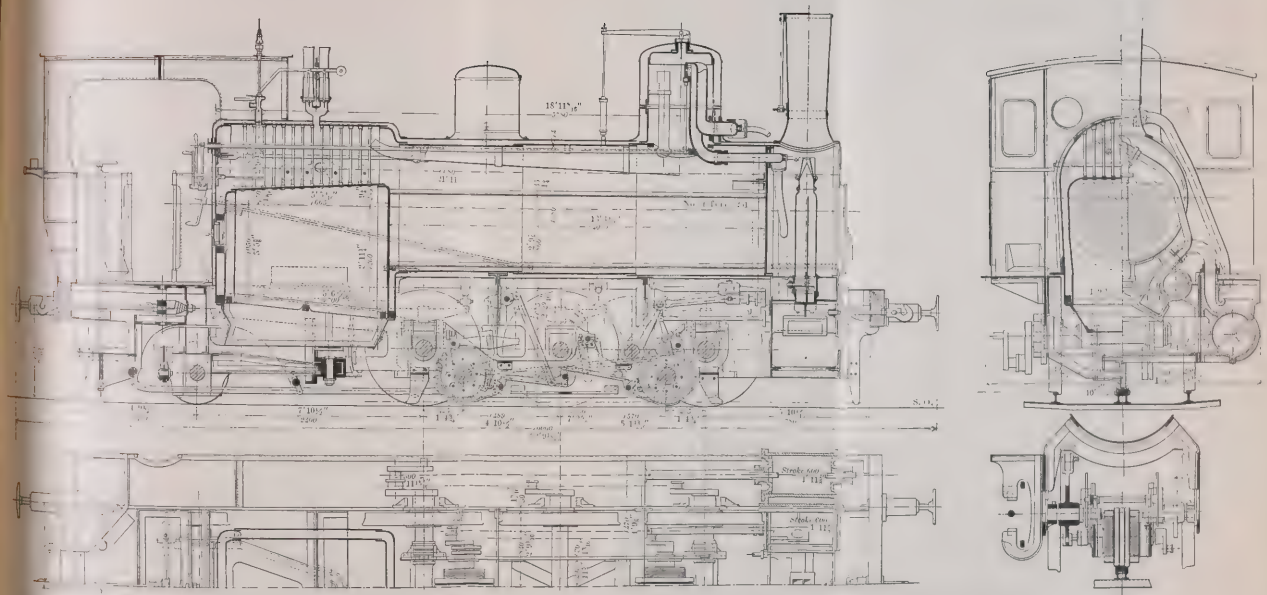
FIG. 297.



[BURG] ON THE HARZ TO TANNE.

Fig 296.

Fig. 297.



LOCOMOTIVE FOR COMBINED ADHESION AND RACK-RAIL, SYSTEM ABT, FROM BLANKENBURG ON THE HARZ TO TANNE.

Scale 1 . 50.

proper opportunity, develop its full capacity. The profile of a road doing a large traffic should, therefore, be so chosen that the adhesion traction will not be lost, hence the gradients should not exceed 6 or 7%, and the adhesion engine should, to the full capacity of the adhesive friction, assist the rack engine in ascending those grades. On light grades the locomotive should develop the same total efficiency as it does on steep grades, hence it should be capable of running with correspondingly greater velocity.

The combination engine having all these qualities, as constructed by Mr. Abt, is one of the most ingenious inventions in railroad engineering: it has already been introduced into all civilized countries of the globe, and has been imitated in many ways. A more detailed description of the locomotive would exceed the limits of this paper, and I refer to the numerous publications on this subject.

Figs. 296 and 297 represent one of the Harz locomotives as described above. It has a total traction power of 13.2 tons, each of the engines developing 6.6 tons. The heating surface of the boiler, which by some engineers was looked upon as too small, has proved to be ample for making sufficient steam to correspond with a tractive power of 13.2 tons. The simultaneous work of four cylinders, with 640 piston strokes per minute, causes an almost continuous exit of steam through the smoke stack, achieving a complete combustion of the fuel, which evaporates 57 to 70 cubic feet of water per mile on a 6% grade, when the locomotive is pushing a train of 148 tons.

It may be interesting to mention some of the rules that were laid down for the locomotive engineers of the Harz railway.

a. UP TRIP.

Before the locomotive enters the rack rail from an adhesion line, the engineer opens a little the throttle of the rack engine, setting the cog wheels slowly into motion before the locomotive reaches the entering rail. It is true the cog wheels would come into correct contact with the rack teeth even without previous motion, but when they are slowly revolving the entering is smoother and noiseless. As soon as the locomotive is fully on the rack rail, the engineer must work the rack engine with all its power. When the locomotive comes near the end of a rack rail, the throttle of the rack engine must be closed to prevent the cog wheels from revolving when directly over the entering rail, in order to avoid an

unnecessary noise by their possible striking against the shortened and rounded teeth of the latter.

b. DOWN TRIP.

The down hill motion is regulated by air compressed in the steam cylinders. Before going down the steam of the rack engine must be shut off, and the locomotive must proceed with the adhesion engine *alone* to a point where the train would begin to descend by its own gravity. Immediately on reaching this point the valve gear must be reversed, so that the motion of the adhesion engine is contrary to the motion of the locomotive. This sets the adhesion air brake in operation, with which the speed of the train is regulated. Shortly *before* entering a rack line, the engineer sets the rack engine slowly into motion in the *same* direction as the motion of the locomotive, but as soon as the entering has fully taken place the throttle of the rack engine must be closed *immediately*, and *in the same moment* the valve gear must be reversed in order to work the air brake of the rack engine, which combines with the adhesion air brake for regulating the speed. With the help of these two (respectively four) cylinder air brakes, the down trip can be accomplished *in perfect safety, without the least danger!*

The proportionate work of the air brakes of the two engines is to be regulated in the same way as the steam pressure is proportioned during the up trip, hence on grades where the rack engine works to its full capacity in going up, the rack air brake must work to its full capacity in going down, and the adhesion air brake assists only to the capacity of the adhesion friction. When the locomotive comes near the outlet of a rack rail, the efficiency of the adhesion air brake must be enhanced, and the valve gear of the rack engine must be reversed so that its motion is in the same direction as the motion of the train. This can be done without endangering the descent, because the ends of all rack grades and the adjoining ends of the adhesion grades are so arranged that the adhesion air brakes alone are sufficient for holding the train.

If for any cause whatever one or the other of the air brakes should not work satisfactorily, the lever brake will at once be put into action.

The Abt system, in spite of having been invented but recently, has found already such an unusually great number of applications for mountain roads with large traffic, that a description of the operating methods as adopted on the Harz railway may be of general

interest. At the same time I will describe the operating methods on a Riggenbach ladder road, and as example will select the Höllenthal (= The valley of hell) railroad in the Black Forest, Baden. This road was built in comparatively recent times and accommodates a heavier traffic than any other ladder road. When I designate it with the name of Riggenbach system I may be censured in certain circles, because Messr. Klose & Bissinger claim to have made certain improvements in Riggenbach's rack and patented them; but their improvements are by no means characteristic nor of any importance, hence their rack rail can properly be called the Riggenbach, Marsh, or simply ladder system.

A comparison between the operating methods of the Harz and Höllenthal railways will show the difference of opinion between the different managements which on one side has resulted in simplifying, and on the other side in complicating the operations, and it will also show some decided advantages derived from the Abt system and disadvantages inherent to the ladder system.

MODE OF OPERATING

THE HARZ RAILWAY ON THE ABT SYSTEM.	THE HOELLENTHAL RAILWAY ON RIGGENBACH'S SYSTEM.
1. THE GRADE ROUNDINGS CONSIST OF CURVES OF	
6,562 feet (= 2,000 m.) rad.	1,066 feet (= 325 m.) rad.
2. THE ROLLING STOCK CONSISTS OF	
Standard cars of the same type as used on all German railways. Therefore, any car of the Harz railway can be used on any other German railway, and any passenger or freight car of standard gauge can be used on the Harz rack road without difficulty and without complicating the operation. Special cars are not needed and do not exist. *The wheel base of the cars is unlimited.*	Two kinds of cars, viz. regular cars of the same type as used on the other Baden railways, and special Höllenthal cars provided with pinion (or cog wheel) brakes. Of the latter kind * there are : 15 passenger cars, 4 baggage " 6 box " 3 platform " The regular Baden standard car can only be used if the *wheel base does not exceed* 14 feet 9 inches (= 4.5 m.).

* For a description of these special cars, the construction of the pinion brake, the bearing springs, the frequent derailments, etc., see *Organ für die Fortschritte des Eisenbahnwesens in technischer Beziehung*, vol. xxvi. part 4. 1879.

3. Method of Moving the Cars.

On the Harz railway the locomotive is placed always at the lower end of the train, hence, in going up hill it pushes the cars, and in going down hill it holds them back. The arrangement of pushing, besides being safer than pulling, and offering other advantages, was a necessary result of the insufficient strength of the draw-bars of the standard cars. These draw-bars cannot safely be strained with more than 7 or 8 tons, while the tractive force of the locomotive amounts to 13.2 tons on a 6% grade, or 3.3 tons for moving itself and 9.9 tons for moving the train.

On the Höllenthal road the trains are always *pulled*. This arrangement has not only the disadvantage of making the train weight dependent upon the strength of the draw-bars, but it necessitates also other complications of which the management of the Harz railway is entirely free. One of the principal inconveniences is caused by the employment of extra pinion cars for braking purposes, as will be described later on.

4. Arrangement of Trains.

The trains on both railways are either "mixed" trains (consisting of freight and passenger cars), or freight trains, or passenger trains. The latter are run generally only during the summer months.

The Admissible Gross Weight of the Trains.

For *all* trains on the Harz railway, 148 tons, exclusive of the weight of the locomotive. The number of cars on passenger trains represent 24 wheel axles.

The trains ascending the maximum grade of 6% cause a pressure of 15,400 lbs. (= 7,000 km.) on the teeth of the rack.

The total resistance being 26,400 lbs., it follows that the adhesion traction is 11,200 lbs., or the proportion of the rack traction to the adhesion traction is as 7 to 6.

For mixed and passenger trains on the Höllenthal railway, 110 tons; and for freight trains, 130 tons, exclusive of the weight of the locomotive.

The maximum pressure on the teeth of the rack, on a 5.3% grade, is 5,500 lbs. (= 2,500 kilo).

The locomotives are heavier than the Harz locomotives, and a proportionately much greater service is required of the adhesion engines than of the rack engines. The proportion of the rack traction to the adhesion traction is as 2 to 6.

The considerably lighter trains on the Höllenthal road than on the Harz road are partially a consequence of the method of pulling the cars, the draw-bars not admitting greater strains; and partially necessitated by the weakness of the rack teeth which would not admit much heavier pressures. This latter circumstance is the reason why the greater part of the traction has been assigned to the adhesion and only a little to the rack service. If the trains were pushed on the Höllenthal road, and if the locomotives would work their rack and adhesion engines in the same proportion as the Harz locomotives are working, and if the ladder rack had sufficient strength to withstand the pressure, the Höllenthal locomotives would be capable of moving trains of 160 tons.

In arranging the trains care is taken that always the first and last car are provided with adhesion brakes.

The passenger, mail, and baggage cars are grouped together and the freight cars are distributed indiscriminately. The distribution of the other brake cars is also immaterial, but about one-third of all axles in the train should be provided with brakes.

The whole train arrangement, therefore, is very simple and free from any inconvenient limitations.

All the cars of the Harz road can be used on any other German railway, and any kind of a German railway train, provided with an Abt locomotive, can run over the Harz road.

The speed of the trains, as determined by regulation, is as follows :

Going up. 9.3 miles (= 15 km.) per hour on the adhesion lines and unlimited on the rack lines. Usually it does not exceed 7 miles, but on trial trips it has been as much as 16 miles per hour over the 6% grades.

Going down. 12.4 miles (= 20 km.) on adhesion lines with 2½% grades and 15½ miles (= 25 km.) on grades less than 2½%. On rack lines the speed is limited to 6.2 miles (= 10 km.) per hour.

The arrangement of mixed trains on the Höllenthal road is the following : Locomotive, freight cars, mail or baggage car, and lastly the passenger cars. The latter must be placed at the end of the train because these are the cars provided with special pinion brakes, while the freight cars are generally standard cars from any other railroad system which have neither pinion brakes nor the "Schmidt" brake, which is customary in Baden.

To place such freight cars, frequently loaded with timber, behind the passenger cars, appeared to the managers too dangerous.

One quarter of all car axles must have adhesion brakes, and one-half of all passenger cars must be provided with pinion brakes.

Passenger trains consist of locomotive, baggage car, and passenger cars. The cars carrying pinion brakes must be equally distributed in the train, and the last car must always have a pinion brake.

In freight trains there is always a box car with pinion brake running over the whole line, placed between locomotive and freight cars. On the rack lines, however, an extra platform car with pinion brake is added, which car is frequently taken off when the train reaches the adhesion line, and, therefore, is rarely loaded with anything else but tools or the like.

Half of all freight cars must be provided with adhesion brakes.

None of the special cars necessary for the Höllenthal road can run on another railroad (except the pinion brake gear be removed), and no train from another German railway can run over the Höllenthal road except several of the special Höllenthal cars are distributed among the other cars.

The speed of the trains running over the rack lines, either up or down, rarely exceeds 5 miles per hour.

5. Transportation of Logs.

Long logs are transported in accordance with the Prussian standard regulations.

The ends of the logs are supported by short cars called "stool cars" which have pivoted platforms provided with numerous pointed iron pins. The logs rest on these pins which press into the wood and hold the timber in place, which therewith forms the coupling between the two cars. No other coupling is used. This whole arrangement is similar to the construction of the regular American cars. The bogie trucks are analogous to the stool cars, and the body of the car, pivoted over the center of each bogie, is analogous to the load of logs. The weight of one timber load is 33,000 lbs. (=15,000 kilo), and *three pairs* of stool cars with their load of logs are admitted in one mixed or freight train. Until the end of 1892 over 3,000 pairs stool cars with timber, as described, have been transported over the Harz road without accident.

An exact profile of the Harz railway, with cross sections and details of substructure, is shown on plates 22 and 23.

The manner of transporting logs is the same as on the Harz road, but the managers of the Höllenthal road do not trust the efficiency of the iron pins projecting from the stool car platforms, fearing that the car might slip from under the timber and cause an accident. As the distance between two stool cars is about 55 feet for transporting logs of 95–100 feet length, it is out of question to connect the cars with a single stiff coupling 55 feet long, hence this length is subdivided into a number of short couplings which are made possible by the employment of so-called "auxiliary stools." These auxiliary stools consist of strong iron beams with steel pins projecting from their upper side, with lugs at their lower side and with chains at the ends. These beams are pressed with screwjacks against the under side of the timber-load so that the steel pins take firmly hold in the wood. Then the chains are passed around the load and drawn tight by means of an adjustable screwhook, and finally a series of stiff couplings are attached to the lugs of the auxiliary stools and to the ends of the stool cars.

By these means one continuous stiff coupling is established which makes the detachment of one or the other of the stool cars an impossibility. The weight of the auxiliary stools and stiff couplings for one load is 2,200 lbs., which is about 5% of the total load of 44,000 lbs.

On rack lines only *one pair* of stool cars with its load of logs is allowed in one train.

THE EISENERZ-VORDERNBERG RAILROAD IN STYRIA, AUSTRIA.

(*See Fig.* 282.)

This road has a single track of standard gauge built on the mixed adhesion and rack systems after the example of the Harz railway. Its total length is 12 miles (= 19½ km.), of which 2.9 miles (= 4.9 km.) are adhesion lines and 9.1 miles (= 14.6

km.) rack lines. The sharpest curve has a radius of 590 feet (= 180 met.), and the steepest grade is 7.1%.

SUPERSTRUCTURE.

The rack rail track and all switches rest on iron crossties after Heindl's system; the adhesion track and the station tracks are supported on wooden ties.

The soft steel ties for the rack rail track are 7 feet $10\frac{1}{2}$ inches (= 2.4 m.) long, $3\frac{5}{32}$ inches (= 8 cm.) high, on the bottom 9 inches (= 23 cm.) and on top $5\frac{1}{16}$ inches (= 13 cm.) wide, and weigh per piece 123 lbs. (= 56 kilo). The switch ties vary in length, and are 4 inches (= 10 cm.) high, $10\frac{1}{4}$ inches (= 26 cm.) wide on the bottom and 6 inches (= 15 cm.) at the top, and weigh per foot 20 lbs. = $29\frac{1}{2}$ kilo per met.

The rack rail is secured to the ties with screw bolts and clamps.

The rack consist of two rows of bars, each 5 feet $10\frac{1}{2}$ inches (= 1.796 m.) long and $1\frac{1}{16}$ inches (= 27 mm.) thick, weighing per piece 78 lbs. (= $35\frac{1}{2}$ kilo).

The distance between the bars is $1\frac{9}{16}$ inches (= 40 mm.), and the crossties supporting the chairs are 35 inches (= 90 cm.) apart from centres.

EQUIPMENT.

The rolling stock consists of eight locomotives built after the pattern of the Harz locomotives. They have three coupled adhesion axles, a laterally movable truck axle, an inside frame and outside wheels (Hall's system). The frame supporting the rack wheel mechanism, which consists of two coupled rack wheel axles, rests on the first and second adhesion axles. The service weight of the locomotive is 62.7 tons, of which each adhesion axle carries 16.1 tons and the engine truck 14.4 tons.

The capacity of the tender is 212 cubic feet = 6 cubic m. The tractive power of the rack engine is 16,000 lbs.

The regular trainweight is 121 tons going up and 132 going down, but freight trains transporting exclusively ores down hill have a weight of from 143 to 154 tons.

All trains are pushed by the locomotives, and it will be noticed that, in spite of a 7.1% grade, the weight of the trains is greater than on the Höllenthal road with but 5.3% grades.

Besides eight locomotives, the rolling stock of the railroad company consists of 60 specially constructed iron cars for the trans-

portation of ores, eight passenger cars and four mail and baggage cars, all built on the pattern of the Austrian government railways standard cars without any special brakes or other extra arrangements.

THE SARAJEWO-KONJICA RAILROAD IN BOSNIA.

This road, built on the Abt combination system, has several specially interesting features. It forms a part of the narrow gauge road which runs for 277 miles, from north to south, through whole Bosnia and Herzegowina on the line: Bosnisch, Brod, Sarajewo, Mostar, Metcovic, and gives the principal means of communication for the whole country. The gauge is 2 feet 6 inches (= 76 mm.). It crosses the Iwan Mountains between the stations Sarajewo and Konjica by means of an Abt combination track, with a maximum grade of 6% on one side of the mountain and 3½% on the other side. The total distance between Sarajewo and Konjica is 35 miles (= 58 km.), of which 11.7 miles (= 18.8 km.) are provided with Abt's rack rail. The total difference in level between the stations Konjica and Iwan (the summit of the mountain range) is 2,056 feet (= 627 met.), which height is ascended almost exclusively by the rack gear in a distance of 10.8 miles (= 17.4 km.). The maximum adhesion grade on this portion of the road is 1½%. The radius of the sharpest curve is 405 feet (= 125 m.).

The locomotives are tender locomotives, with a complete mechanism for adhesion service and an independent mechanism for rack service. The whole engine is supported on four axles, viz., three coupled adhesion axles firmly connected with the engine frame, and one loose axle supported on a bogie truck and capable of placing itself in a radial position when going around curves.

The frame supporting the cog wheels is suspended from the first and third adhesion axle inside the engine frame. The cog wheel axles are placed between the first and second and the second and third adhesion axles. Each cog wheel consists of two disks, corresponding to the two bars of the rack, which are driven by two cranks and rods, the latter receiving their motion from a common crosshead.

The weight of the engine, when in service, is 34 tons, of which each adhesion axle carries 8.8 tons. The water tank contains 97 cubic feet (= 2.75 cubic m.); the fire box 70.6 cubic feet (= 2 cubic m.), and the efficiency of the locomotive was guaranteed to be sufficient for pushing a train of 121 tons up a gradient of 3½%

with a velocity of 5½ miles per hour. In reality this velocity is maintained with trains weighing 132 tons. On the 6% grades the regular train weight for one locomotive was to be 66 tons, but often it reaches 71 tons. In place of splitting the trains in two, full trains of 121 to 132 tons are taken up the steep grades by two locomotives, one pulling, the other pushing.

According to the report of Mr. Schmack, the superintendent of the road, this "double team" works very satisfactorily without causing any jerks or shocks. The regular way of operating is by the locomotive pulling the cars, and not pushing.

All standard cars on the Bosnia and Herzegowina narrow gauge railways have three axles provided with the automatic "Hardy" air brake. One-half of all cars in passenger trains as well as in freight trains must be provided with air brakes.

SAFETY IN THE OPERATION OF RACK RAILWAYS.

The safety on rack roads, in spite of the steep grades, is almost absolute. No accident is on record that has happened on any of the large rack roads. The Harz railway has now been in operation for eight years, during winter and summer, without any disturbance or interruption. During the severe winters in 1886–7, 1887–8, 1892–3, when the snow lay three feet on a level, the rack rail proved to be the most valuable assistant for keeping up traffic. There were only two or three days, when the snow was still deeper, that, temporarily, the trains ceased running.

The Eisenerz-Vordernberg Railroad reports:

"Only the most unfavorable conditions of winter weather, as happened in 1891–2, could compel us to interrupt traffic for a short time; but even opponents to the rack system must confess that we held out much longer and under more trying circumstances than could have been done by the adhesion system. We have frequent and terrible snow storms, which we master with the help of the rack rail and snow ploughs, but when avalanches come down the mountains and cover the road with snow to a depth of 15 to 25 feet (like in 1892), we must, of course, temporarily cease running. In the present winter we had much snow, but no avalanches. Our winters last three-quarters of the year, and for one-quarter of the year it is cold!"

A gentleman who was traveling over the Sarajewo-Konjica railway wrote me last February:

"My trip through Bosnia was very interesting. With the ther-

mometer at 24° Fahr. below zero and with 6½ feet of snow on the ground, we crossed the Iwan mountains on the Abt railroad. Below, in the level country, railroad travel was interrupted already for a week, while in the mountains traffic was kept up and trains made their regular trips. Only once trains ceased running for half a day, because a train was fast in the snow way down in the Marenta valley.

"The train on which I crossed the Iwan mountains had to plough its way through 18 inches of fresh fallen snow which at certain places had drifted to a depth of 3 feet 7 inches. Ahead of the train went a locomotive with a snow-plough; there was no delay, and we arrived at every station on schedule time. For a length of 37 miles the snow was three feet deep, even on the embankments, and the inhabitants of the Iwan district are enthusiastic over the success of this railroad, which it would have been impossible to operate during this long winter without the help of the rack rail.

"This remarkable result has been achieved on a road with only 2 feet 6 inch gauge."

CONSUMPTION OF FUEL.

The Harz railway between Blankenburg and Tanne uses, exclusively, coal from the Dahlhausen mine in Westphalia. One pound of this coal evaporates 11 pounds of water, and the average consumption of coal during the year 1891 was 62 pounds per train mile (17.4 kilo per train kilometer). On the adhesion road Halberstadt-Blankenburg with 1% grades, this consumption during the same year amounted to only 41.3 lbs. per train mile.

The locomotives of the Eisenerz-Vordernberg Railroad require 89¾ lbs. of Frohndorf coal or 79½ Libuschin coal per train mile, but one pound of the former coal evaporates only 5.39 lbs. and of the latter 6.07 lbs. of water. If Dahlhausen coal were used on this road, the average consumption would be 71 lbs. per train mile, which is a little more than on the Harz road on account of steeper grades and proportionate smaller lengths of the adhesion lines.

TRAFFIC.

The following table gives a general synopsis of the traffic on the above described rack railroads:

	Harz Railway in 1891.	Höllenthal Railway in 1891.	Eisenerz-Vordernberg R. R. in 1892.
Miles run.....	52,933 (= 85,377 km.)	78,005 (= 125,815 km.)	55,180 (= 89,000 km.)
Number of passengers carried.....	72,766	257,706	23,926
Tons of freight....	189,890	140,751	261,782
Operating expenses	$55,671 (= 222,684 Marks) (including general management.)	$78,101 (= 312,403 Marks) (exclusive of general management.)	$75,300 (= 150,600 Austrian florins.)
Expenses per train mile.....	$1.05 (= 2.6 Marks per km.)	$1.02 (= 2.52 Marks per km.)	$1.36 (= 1.68 Florins per km.)

The running expenses on the Eisenerz-Vordernberg road appear to be very high, but they only *appear* so, because in reality they are very low if all conditions are considered. The average grade on this road is 4.7%. If it had been built on the ordinary adhesion system with an average grade of 2½%, its length would be about double its present length. The number of train miles for the same amount of traffic would consequently be twice as great, and the expenses be correspondingly increased.

According to statistics of the general Austria-Hungary railways, the average operating expenses are $0.92 per train mile. Assuming this figure as the cost of running an adhesion road on the line Eisenerz-Vordernberg, which is a low estimate on account of 2½% being a steeper grade than the average on the Austria-Hungary railways, the total running expenses would have been $101,531 or $26,231 more than the actual expenses were. In other words, if the running expenses on the existing Eisenerz-Vordernberg railroad had been $1.84 per train mile, they would not be greater than the cost of running an adhesion road between the same points. In reality the expenses were only $1.36, or a saving of 48 cents, per mile by the use of the Abt rack rail.

A comparison between the stated expenses per train mile of different railroads of different character would convey a wrong impression. In order to obtain a correct idea of the financial value of different railroads it is necessary to place the different circumstances upon the same base. A comparison between the results thus obtained would demonstrate economical advantages in the construction of rack railways similar to those proved in the case of the Eisenerz-Vordernberg road.

Comparing the efficiency between the Harz and Höllenthal railways, we notice from the table above that the latter road transported 184,940 more passengers and 49,139 less tons of freight than the former road. Assuming the weight of one passenger to be 165 lbs., 184,940 passengers are equal to 15,258 tons of freight, which, added to the other freight carried by the Höllenthal road, will still leave a difference of 33,881 tons of useful net weight in favor of the traffic on the Harz road. The *smaller* traffic on the Höllenthal road required also a *greater* number of train miles than the *larger* traffic on the Harz road required, showing, therewith, the advantage of the heavier trains on the latter road.

Assuming that all passengers and all freight were transported from one end of the line to the other end, the cost of transportation per ton mile would be $2\frac{22}{100}$ cents on the Höllenthal road, and $1\frac{1}{2}$ cents on the Harz road. The latter figure includes also all the expenses of the general management, while the first figure represents only the actual running expenses exclusive of the general management of the road. This shows, from a financial point of view, the superiority of the Abt system, and of the method in operation on the Harz railway over the Riggenbach system, and the way it is managed on the Höllenthal railroad.

COST OF SOME MOUNTAIN RAILROADS, INCLUDING THEIR LOCOMOTIVE EQUIPMENT.

a. Adhesion Roads.

The Semmering road has cost per mile.....$484,000
(= 600,000 florins per kilometer.)

The Gotthard railroad cost per mile.....$484,000
(= 1,500,000 francs per kilometer.)

The Brenner road cost per mile.....$322,000
(= 400,000 florins per kilometer.)

The Arlberg road cost per mile.....$244,400
(= 303,000 florins per kilometer.)

b. Mixed Rack and Adhesion Roads.

The Eisenerz-Vordernberg road cost per mile.....$225,800
(= 280,000 florins per kilometer.)
The Höllenthal road cost per mile.....$100,800
(= 250,000 marks per kilometer.)
The Harz railway, Blankenburg-Tanne, cost per mile.....$52,000
(= 128,800 marks per kilometer.)
The Sarajewo-Konjica road (narrow gauge) cost per mile .....$39,000.
(= 96,800 marks per kilometer.)

These figures show a marked difference of cost in favor of rack roads as compared with adhesion roads, but this difference would be still greater if we compare the actual cost of these rack roads with adhesion roads having 2½% maximum grades, supposed to be built between the same termini. The line would be at least twice as long and the cost per mile would be greater, hence the cost of an adhesion road would be more than twice the cost of a combination rack and adhesion road.

RACK RAILWAYS IN COURSE OF CONSTRUCTION.

The most important railway on the Abt system, at present in course of construction, is between Beirut and Damascus, in Syria. The total length of this road will be 87 miles (= 140 km.), 18.6 of which (= 30 km.) will be provided with a rack rail for ascending and descending the Lebanon mountains which extend between the two named cities. The gauge will be 3′ 5¼″ (= 105 cm.); the steepest adhesion grade will be 2½%, and the steepest rack grade 7%. The total cost of the road has been estimated at $6,000,000 (= 30,000,000 francs), or at $68,957 per mile (= 214,287 francs per kilometer).

OTHER PROJECTS.

A new project, promoted by the banking firm Morson, of Lausanne, has been worked out by Mr. Chappius, C.E., for crossing the Simplon Pass from Brieg, in Switzerland, to Domo Dossola, in Italy. The gauge is to be standard; the steepest grade will be 6% for rack service, and 2½% for adhesion service. The smallest radius for curves has been limited to 656 feet (= 200 meters).

This road, if built, will be especially interesting for being operated with electric motors, for which the Rhone and Cairasca rivers are to furnish the power. The road will have a length of 31 miles (= 15 km.), and its cost is estimated at $8,000,000 (= 40,000,000

francs), which is equal to $257,640 per mile, or 80,000 francs per kilometer.

If an adhesion road were to be constructed between the same points its cost, as estimated by the projectors, would be $18,000,000, or more than twice the cost of a rack combination line.

ADVANTAGES OF RACK RAILWAYS.

The royal Italian State Office of Public Works appointed in 1892 a commission for examining and studying the system of rack railways, and to report upon the advisability of its application with reference to the topography of Italy.

The commissioners were Mr. Artomi di Sant Agnese, inspector of civil engineers, and Mr. Nicoli, inspector of railways. From the report of these gentlemen I quote the following concluding remarks:

"After having thoroughly studied this subject we have come to the final conclusion: 1. That rack railways offer an excellent means for overcoming steep inclines which are beyond the limit of adhesion, and that they make railroad communication profitably possible in mountainous regions where adhesion roads would require the investment of too much capital and would not pay.

"2. That the slow speed of the rack locomotives is favorable for working the engines most economically, and that the speed, though in itself slow, is, relatively considered, about the same as the average speed on adhesion lines.

"3. That it is practical, considered from a mechanical standpoint, for cog wheel locomotives to ascend grades from 3½ to 25%; but that, from an economical standpoint considered, the grade on combination rack roads with large traffic should not exceed 7%.

"4. That the Abt system for roads with large passenger and freight traffic is preferable to any other rack system.

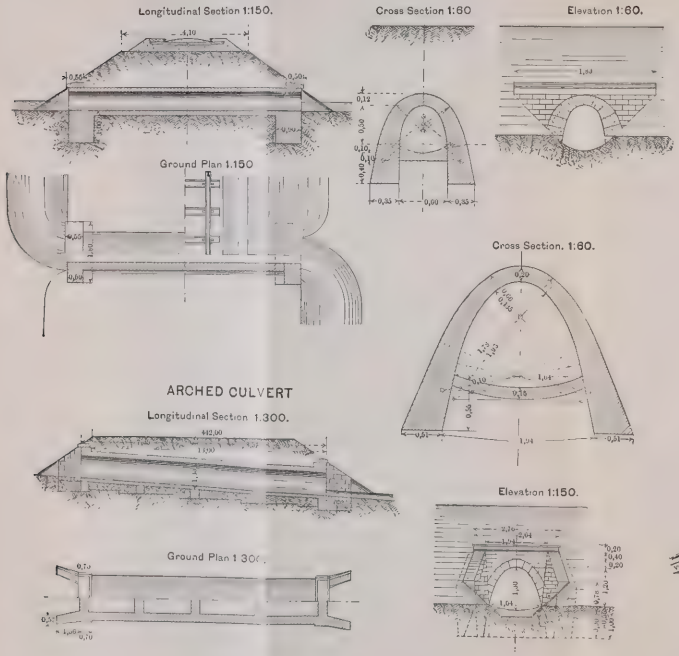
"5. That the efficiency of a rack railway even on very steep grades is considerable, but on grades of 6 to 7% its efficiency is equal to an adhesion road of 2½%.

"6. That the total operating expenses of a combination rack railway are smaller than those of an adhesion road between the same points; hence, that rack systems can favorably compete with adhesion lines.

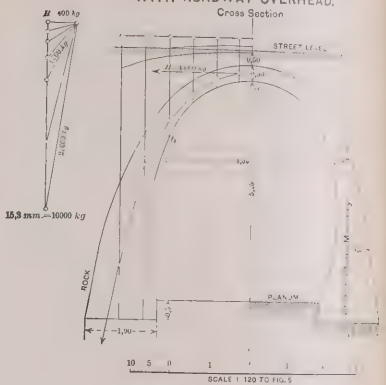
"7. That Italy contains many locations where the application of the Abt rack system would be advisable from a technical as well as from an economical point of view."

FIG. 300.

STANDARD FOR AN ARCHED CULVERT OF 0,6 M L.W.



PORTAL OF THE BIELSTEIN TUNNEL WITH ROADWAY OVERHEAD.



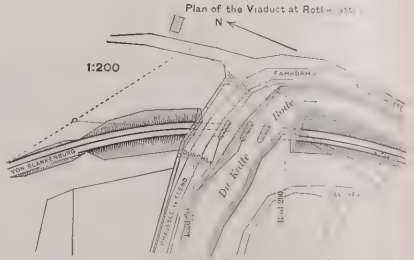
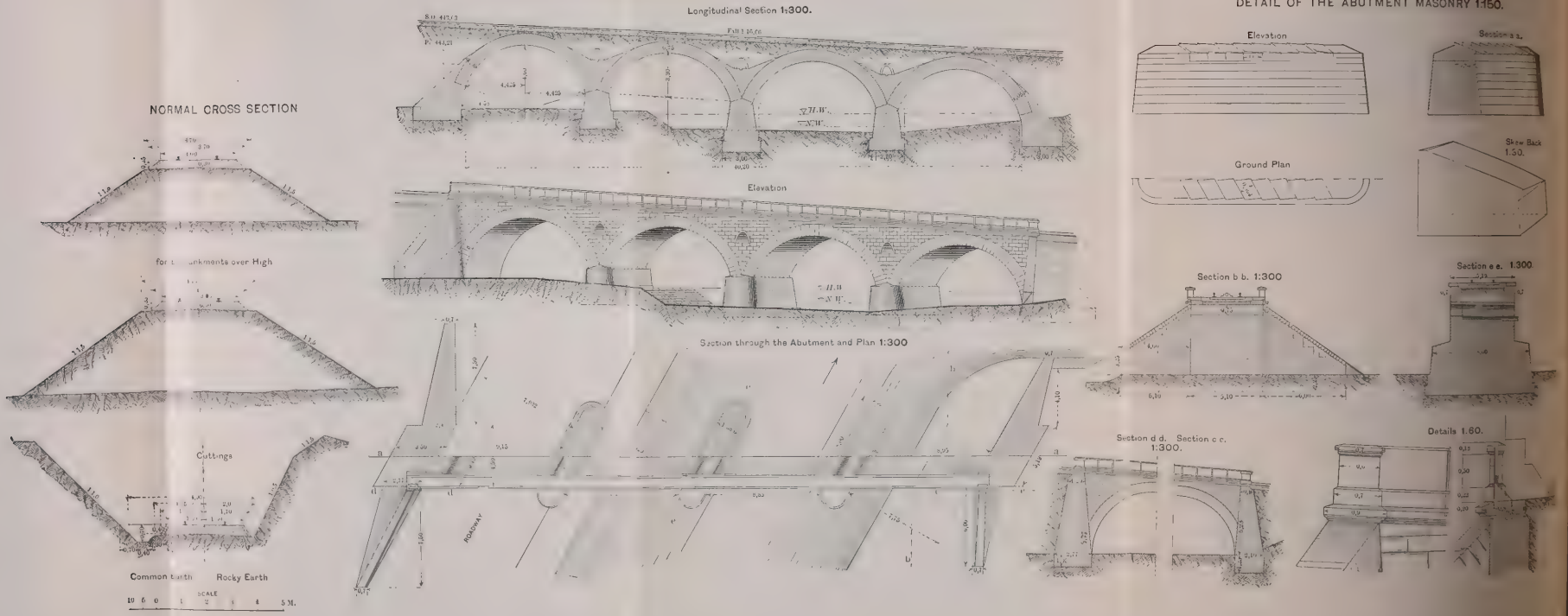


FIG. 299.

ARCHED VIADUCT FOR BRIDGING OVER THE ROADWAY AND THE BODE AT ROTHEHUTTE IN STATION 187+60



COMBINED ABT-SYSTEM FOR ADHESION AND RACK FROM BLANKEN

LONGITUDINAL PROFILE.

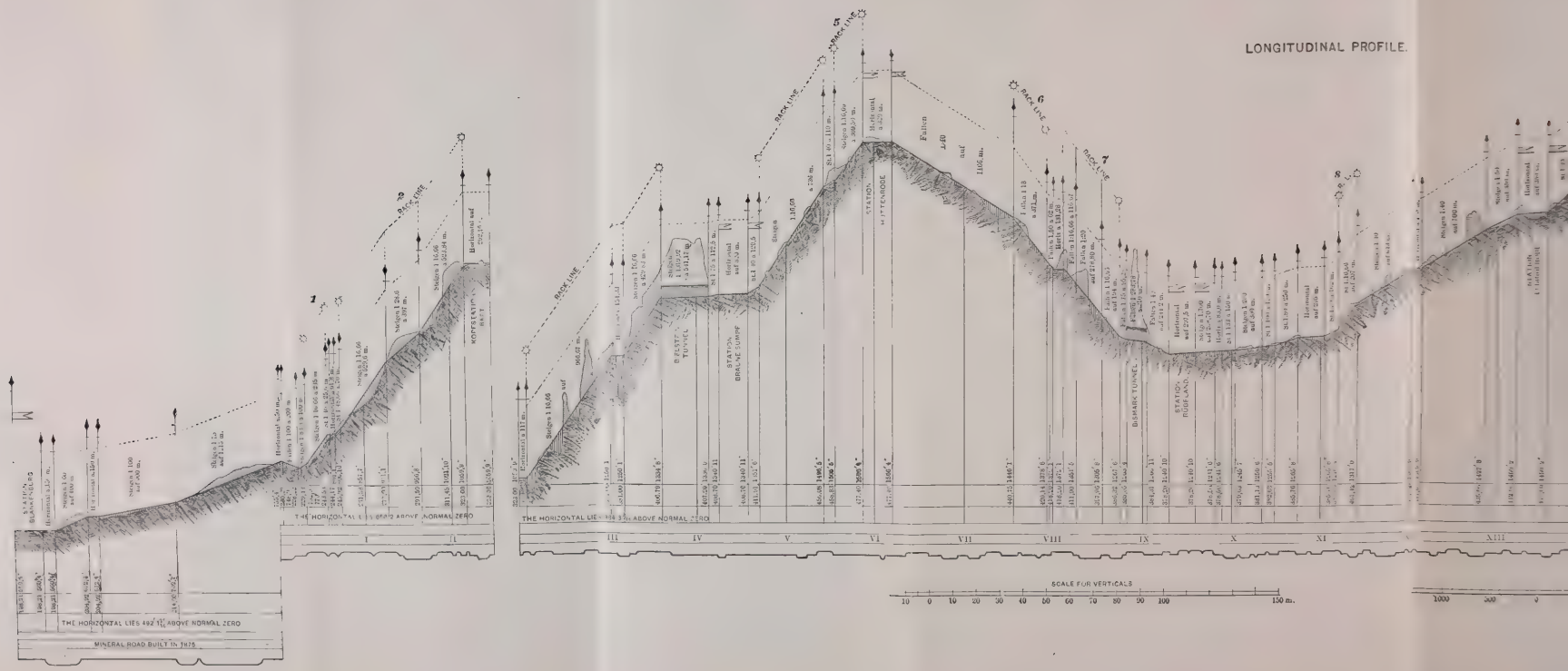
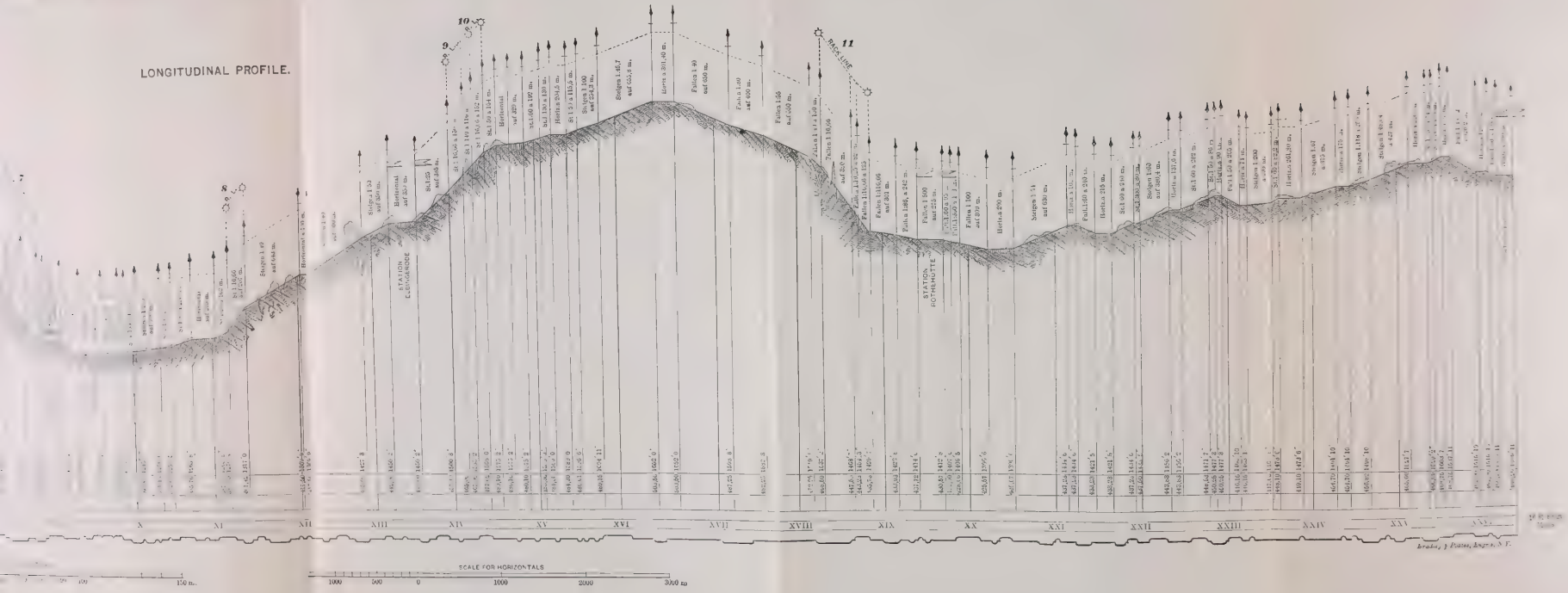

THE HORIZONTAL LIES 492 ft. ABOVE NORMAL ZERO
MINERAL ROAD BUILT IN 1875
THE HORIZONTAL LIES 1312 ft. ABOVE NORMAL ZERO
THE HORIZONTAL LIES 1936 ft. ABOVE NORMAL ZERO
BACK LINE
STATION HÜTTENRODE
STATION BRAUNE SUMPF
STATION HOHEGEISS
BISMARK-TUNNEL
SCALE FOR VERTICALS
10 0 10 20 30 40 50 60 70 80 90 100 150 m.
1000 500 0

FIG. 298.

TEM FOR ADHESION AND RACK FROM BLANKENBURG IN THE HARZ TO TANNE.

LONGITUDINAL PROFILE.



CONCLUSION.

From the facts enumerated in the preceding pages and from my experience in building and operating rack railways, I decidedly recommend the construction of such lines in place of adhesion roads in mountainous regions for the following reasons:

a. The line will be shorter, hence the invested capital will be smaller.

b. The operating expenses are smaller than on an adhesion line of equal efficiency between the same termini.

c. The safety is much greater than on adhesion roads with steep grades.

The Abt system is superior to any other rack system, and its application is especially to be recommended for roads with large traffic and with a profile of 5 to 6% maximum grades for rack service and 2½% grades for adhesion service.

Grade roundings should be made with large radii.

Those interested in the subject will find in the German department of the exhibition at Chicago a model of a portion of the Harz railway, of the rack rail and the locomotive, also a profile of the line with numerous explanations. (Figs. 298 and 299.) An inspection of this model may assist in illustrating and explaining some points which in this paper may not have been made fully clear.

I hope that the preceding pages may contribute towards dispelling the distrust against rack railways, which, in spite of their remarkable success and daily increasing application, still exists in certain circles.

Some regions in the mountains can be brought in railroad communication with the outer world by the application of a rack system, which, without the assistance of the latter, *never* would or could be blessed with this indispensable medium for modern progress.

DISCUSSION.

*Mr. A. von Borries.**—I would say that the rack system works very well on the Hartz. It is very near to my place, and I have often visited it. It is well known that the steam generation of a locomotive boiler depends very much upon the speed. Now, the rack engine runs with a much higher speed than the ordinary engine, because the wheel is much smaller; it is less than half, and the quick running of this engine causes a very high pro-

* Of Hanover, Germany.

duction of steam. Therefore, the boiler generates much more steam than on an ordinary engine. The whole height to be attained in the grade is therefore reached in a much shorter time. I believe this is a very important feature of this engine.

Mr. W. Hildenbrand.—As representative of the Abt system I have received hundreds of inquiries about rack railways, and I am surprised at the general error, even among engineers, concerning the efficiency of this system. As a rule, I noticed that the projectors of such railroads were greatly disappointed about the apparently light train loads and slow speeds with which steep inclines can be operated. I wish, therefore, to say that a rack railway is nothing wonderful, and, theoretically, is not different from any ordinary railway. It simply provides the means for getting the necessary adhesion. The track and rack mechanism has reached such a state of perfection that any desired load with any reasonable speed might be safely taken up a twenty-five per cent. grade, if a locomotive could be constructed to furnish the requisite power. The capacity of a rack railway is limited by the capacity of the engine boiler to produce sufficient steam. In order to make rack railroads more useful and more applicable than at present, it rests with the mechanical engineers to improve the engines in such a way that they can develop more power. This fact was evidently recognized by Mr. Schneider when he sent his paper to *this* Society.

Now, as the question has been discussed about compound and single locomotives, I will say that, so far as my experience goes, compound locomotives are the best. The first engines which were constructed for the Pike's Peak railroad were of the single type. This road has a length of nearly nine miles, with an average grade of seventeen per cent., and maximum grades of twenty-five per cent. The engines, according to the contract, should have run with an average speed of five miles per hour, making the ascent to the summit in about one hour and forty eight minutes; but it was a rare case that they accomplished it in two hours, generally requiring two and a quarter to two and a half hours. Afterwards some compound engines were ordered from the Baldwin Locomotive Works (who also had built the first engines), which gave us a great deal better service, making the trip to the summit easily in one hour and thirty minutes to one hour and forty minutes, and consuming less coal. For this reason I would say that the greatest service could be rendered to the

rack railway system, if the members of this Society would expend their talents and energy in improving the engines so that they will give more power.

The Chairman.—What is the additional cost per mile for the rack, Mr. Hildenbrand?

Mr. Hildenbrand.—In round numbers, about $15,000 per mile for the rack.

Mr. H. H. Suplee.—There is an instance of the use of railways constructed on the combined adhesion and rack principle which is dependent upon the geological features of the country and which may be of interest in this connection. In nearly all of the Swiss valleys the geological formation consists of débris from the avalanches, and broken rock which has from time to time fallen and filled up the bottom. In the earlier mountain railways the roadway was often laid along the edge of the valley, part way up the side, the idea being to obtain as uniform and moderate grades as possible. The result, however, was that the roadway was very frequently disturbed by settling and sliding of the ground beneath it, the filling in of the valley constantly settling and slipping down the sides of the rocks. The later railways have therefore been constructed on the principle of laying the roadway right in the center of the valley, upon the material forming the "filling," or débris, which has in earlier ages fallen into the valley, and which is almost entirely free from settling. This compels the use of steeper grades, the road usually passing up the center of the valley, then turning sharply and climbing right up the steep incline of the mountain to the next valley, thence up the center of that valley, and again up the steep incline, and so on until the top is reached.

This compels the use of alternate moderate and steep grades; the adhesion system is all right for the moderate grades, and the rack must be used for the steeper grades, so that the Abt system is especially adapted for this method of constructing the road.

It is interesting to note that the famous Mont Cenis railway is one of those built upon the edge of the valley and disturbed by settling, so that it is now being relaid along the center of the valley, and the entrance to the Mont Cenis tunnel is being diverged in order to admit the road from this new line. This involves the tunneling of a new entrance into the mountain, and a portion of the tunnel reconstructed until it merges into the line of the old tunnel.

This discovery of the geological requirements of the Swiss railways is, I believe, due to the late Professor Colladon, well known both as a physicist and an engineer; and to him is also due the original discovery of the transmission of light through water, which has been so effectually used in the illuminated fountains at the Exposition.

DXXXVII.*

APPARATUS FOR MEASURING AND REGISTERING QUANTITIES OF STEAM PASSING THROUGH CONDUITS, OR UTILIZED IN STEAM-ENGINES, AND FOR MEASURING AND REGISTERING THE WORK PERFORMED BY STEAM-ENGINES.

BY FRANZ SEILER, MANNHEIM, GERMANY.

THE weight of steam passing during any given period of time through a conduit can be determined, if the weight be known of the quantity of steam which passes through the same cross-sectional area of pipe in a given unit of time, the pressure or density of the steam being assumed to be known in each case, because the weight of the quantity of steam passing in the unit of time is the product obtained by multiplying the volume of steam which has passed the known cross-section by the density of the steam, which is proportional to the pressure. If now the cross-section of passage in the said steam-conduit be assumed to be variable, as by inserting an automatically movable valve, the weight of the quantity of steam will still be the same, whether the volume or the pressure or the density of the steam in the cross-section of passage of the said valve be varied, or only the product of the two factors remains the same. These variations between the volume and the pressures of steam in the conduit must, however, be considered to be known. Now, since the pressure or density (specific weight) of the quantity of steam passing through a steam-conduit in a given unit of time is also variable, there can be constructed from the products of these variable values, from zero to the maximum volume and from zero to the maximum pressure or density, a scale in which the numbers of the weights from these products are proportional to the series of numbers in units, tens, hundreds, etc. If, now, these numerical values, when marked at equal intervals of a scale, represent the weight of the quantities of steam that have passed through the

* Presented at the Chicago meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

steam-conduit, it is possible to construct an instrument or apparatus which shall form these products of the volume of steam and density, or pressure, in an automatic manner, and shall mark the same on a registering mechanism as ordinates of a diagram, or shall add or sum up the same by means of a so-called "integrator."

The invention* consists of a steam-measuring device for the pur-

Fig. 301.

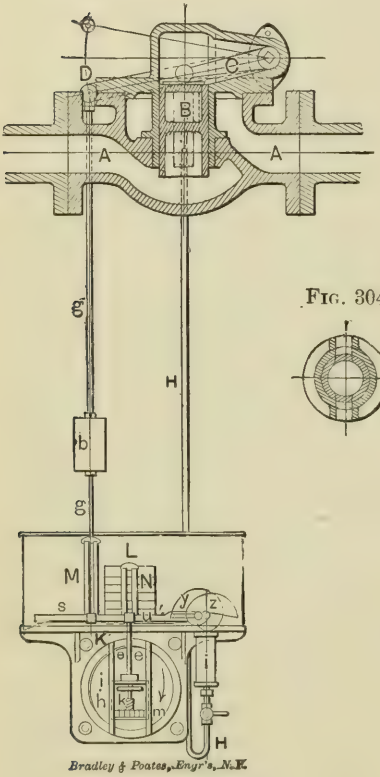
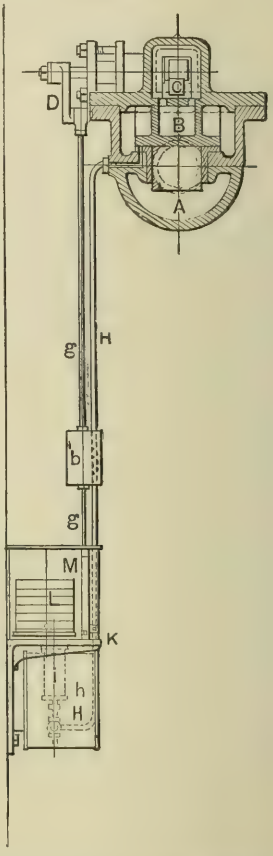


Fig. 304.

Fig. 302.



pose mentioned, composed of an automatically lifting valve, which may be a disk, piston, or flap-valve, and which is gauged for all positions of its lift, and an indicator with a so-called "multiplying mechanism" and recording and indicating device.

* U. S. Patent, 481,287, August, 1892. Patented also in England, Germany, France, Belgium, etc.

The invention also consists in the construction and combination of parts and details, which will be fully described hereinafter, and finally pointed out in the claims of patent.

In the accompanying drawings, Fig. 301 is a front elevation of

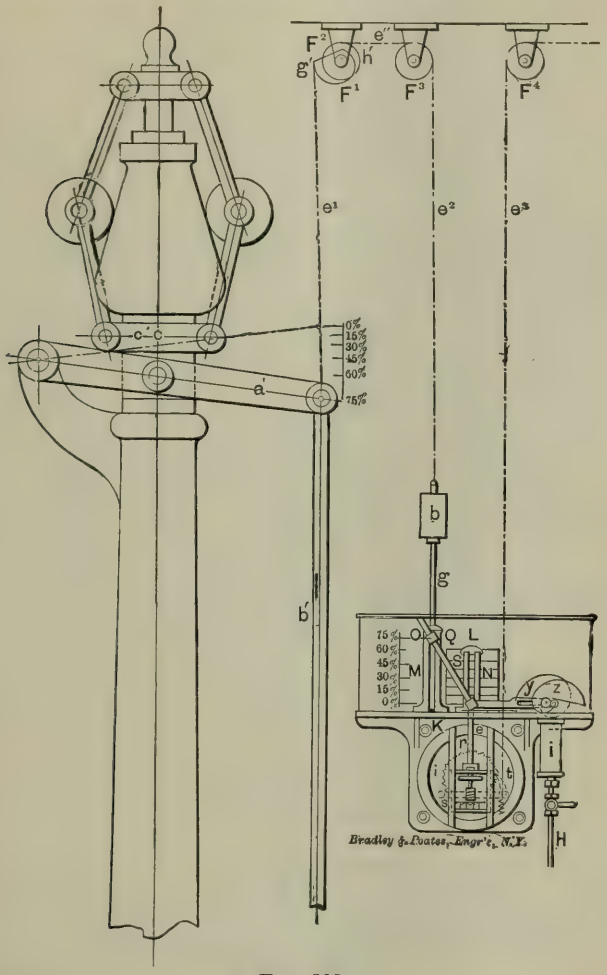


FIG. 303.

my improved apparatus for measuring steam. Fig. 302 is a side elevation of the same. Fig. 304 is a transverse sectional view of the measuring-piston with its seat. Fig. 305 is a front elevation of the recording and integrating apparatus. Fig. 306 is a side elevation, and Fig. 307 a plan view of the same.

Fig. 303 is an elevation of the apparatus as applied to steam-engine governors.

Fig. 305.

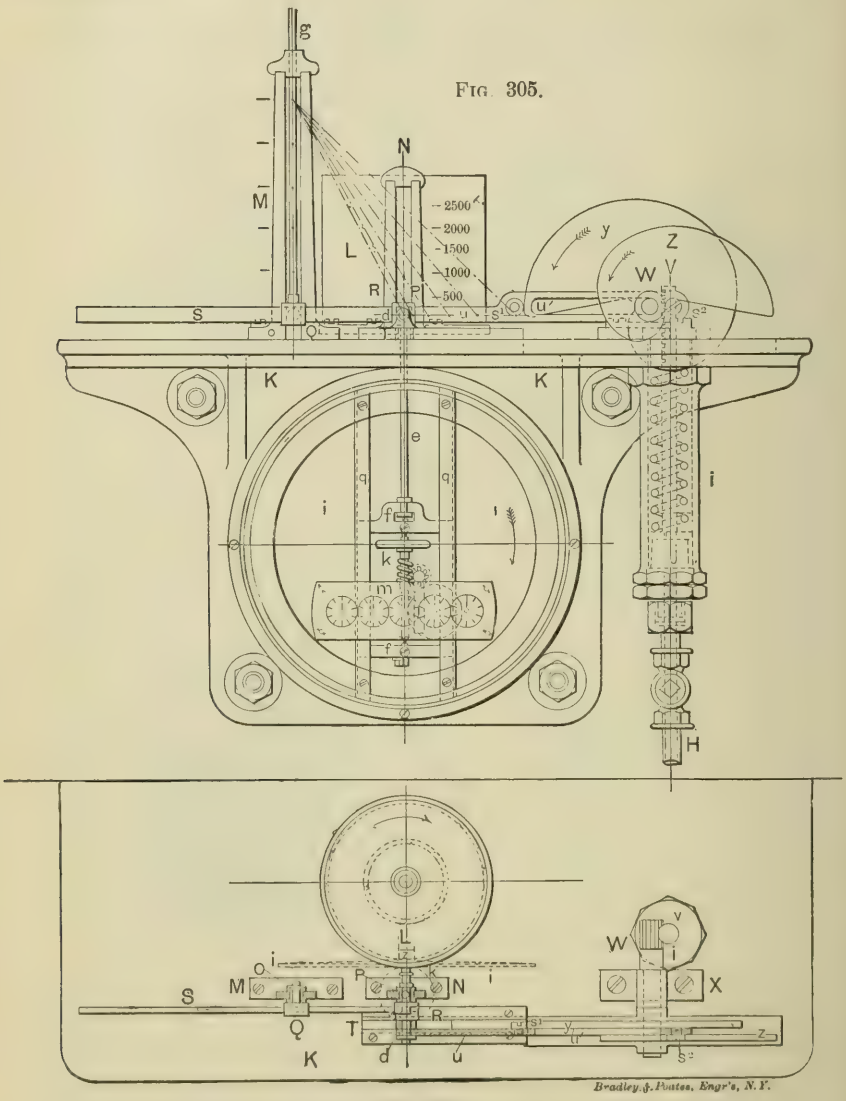


Fig. 307.

The same letters of reference indicate the same or corresponding parts.

There will be first described the apparatus employed as a steam-

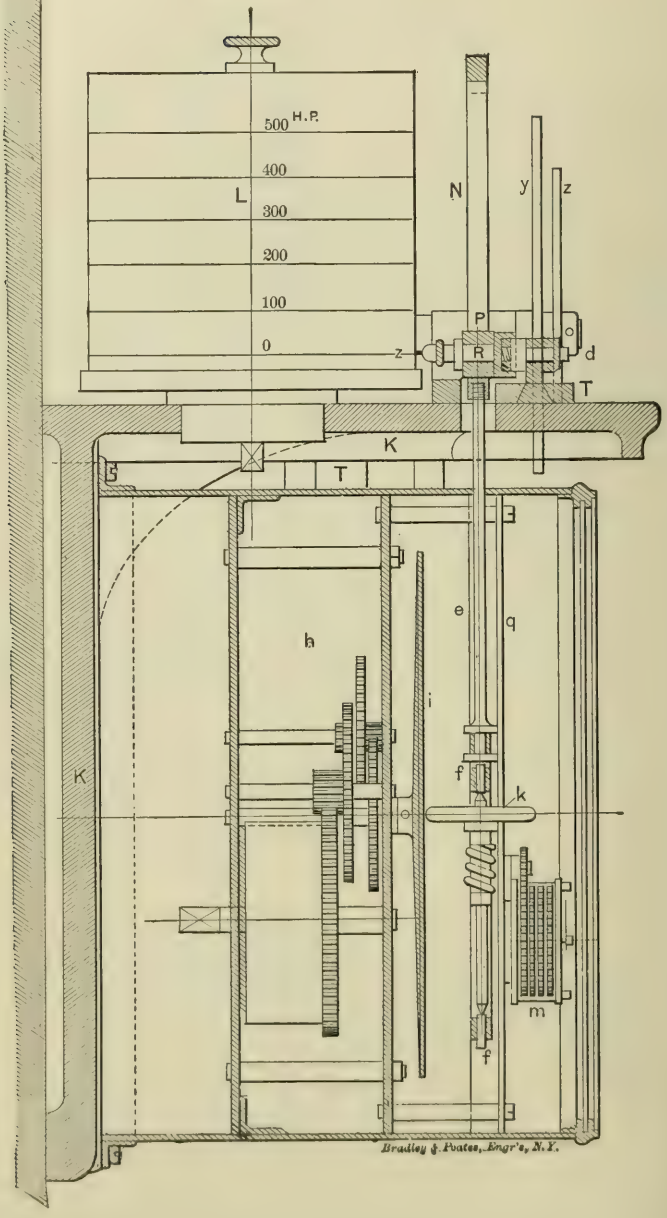
meter for steam-conduits, Figs. 301, 302, 304, and Figs. 305, 306, and 307.

A is a valve-casing with valve *B*, which is shown as a piston-valve (Fig. 304, horizontal sectional view). This casing is arranged to form part of the steam-conduit, the weight or the volume of the steam passing through which is to be measured. *C* and *D* are two levers fixed with an axle, which transmits the lift of the measuring-piston *B* by the medium of the pull-rod *g* to the sliding or guide piece *O*. *H* is a steam-pipe, one end of which passes through the valve-casing, *A*, right up to the valve-seat, and the other end of which leads to an indicator, *I*, forming part of the recording apparatus, for the purpose of transmitting to the indicator the pressure existing between the measuring-piston and its seat.

The recording and the integrating apparatus has direct connection with the multiplying mechanism and marks the products of the volume and the pressures of the steam—that is to say, the variable weights of the quantities of steam—as ordinates in a diagram, and at the same time adds up the same in the counting mechanism of a so-called "integrator" and comprises the following devices, part of which are directly attached to a bracket-plate, *K*. *L* is a recording-drum driven by clockwork, which causes a strip of paper wound on a cylinder, *L*, to rotate past a pencil, *z*, at a suitable rate —for example, once in twelve or twenty-four hours—for the purpose of drawing a diagram. *M* and *N* are upright guides, in which two slide-pieces, *O* and *P*, move up and down. The slide-piece *O* is connected with the measuring-piston *B* through the medium of the pull-rod *g*, provided with a weight *b*, and the levers *C* and *D*. The slide-block *P*, which carries the pencil, *z*, of the recording mechanism, is connected by a rod, *e*, with the sliding frame *f*, or with the planimeter-wheel *k* and the counter mechanism *m*, connected therewith.

In the slide-pieces *O* and *P* are pivot-pins, with guides *Q* and *R*, the latter connected to the slide-piece *P*, carrying the pencil *z*, and through which passes the multiplying or reducing lever *S*, which is movable therein. This lever *S* is mounted on a movable sliding carriage, *T*, by the pivot *d*. The pivot *d* has also connected to it a pull-rod $u\ u^1$, which serves to move the same, together with the lever *S*. Opposite to this mechanism, and screwed to the bracket-plate *K*, is a spring-indicator, the piston-rod *V* of which is formed with teeth at its upper end, and engages with a pinion on a shaft *W*, which is mounted in the bearing *X*, and carries two cams,

FIG. 306.


500 H.P.
400
300
200
100
0
L
N
y
z
P
R
z
d
T
K
T
K
h
e
q
i
f
k
m
Bradley & Coates, Engr's, N.Y.

y and z, which rotate in the direction of the arrow when the indicator-piston or the piston-rod, V, rises. On the pinion and cam shaft W there slides, forward and backward, the movable slotted link u^1, which forms a prolongation of the rod u, according as the stops or pins s^1 and s^2 of the slotted links are moved to the right or the left by rotation of the cams y and z. These cams, y and z, of which one is always opposite the other, are constructed in such a manner that the movements of the slotted link u^1 and the rod u and sliding carriage T, which is connected with the rod u by the pivot d, together with the multiplying-lever S, which is capable of turning and sliding in the slide-pieces O and P and guides Q and R respectively, will correspond to the pressures under the indicator-piston—that is to say, to the steam pressure existing at all times beneath the valve B and its seat.

The integrating device, as can be seen from the drawings Figs. 305 to 307, is arranged under the bracket-plate K. It comprises the clockwork h, which rotates a plane disk i, for instance, once in a minute, and a planimeter wheel k mounted in a straight line, reciprocating frame f, and bearing on the plane disk i; the revolutions of the wheel k being quicker or slower according to its position on the disk i, and the revolutions of the wheel k being transmitted by worm-gear and intermediate wheels to a counter, m. The guide-frame f, which, with the planimeter wheel and counter, is guided under the guide-fillets q, and is pressed by flat springs against the plane disk i, is connected by means of the rod e with the slide-piece P that carries the pencil z, so that the planimeter wheel k follows exactly the same path up and down as the pencil z.

The operation of the complete steam-meter for steam-conduits is as follows: When no steam passes through the conduit—viz., between the measuring piston B and its seat—and there is also no pressure therein, the multiplying mechanism, with the indicator and the recording and integrating apparatus, are in the zero position, as shown in the figures; but as soon as the steam passes through the conduit, between the measuring-piston B and its seat, the piston B rises according to the volume of steam passing. This movement of the valve is transmitted either by the levers C and D and the pull-rod g to the slide-piece O, and consequently the multiplying lever S is raised, together with the slide-piece P, pencil z, and planimeter wheel k. Now, as soon as the steam pressure in the passage area between the measuring-piston B and its seat, and

also under the indicator-piston j, increases, the pivot d of the multiplying lever S, which lever is capable of turning in the slide-pieces O and P, and capable of moving endwise in the guides Q and R, is shifted or caused to move according to the pressure, by means of the rod and slotted link $u\ u^1$, in consequence of the rising of the indicator-piston j and rotation of the cams y and z_1. Consequently there takes place a further rising of the guide R and slide-piece P, which carries the pencil z, and of the guide-frame f, suspended therefrom and carrying the planimeter wheel k. These changes of position of the measuring-piston B of the multiplying mechanism, and of the recording and integrating mechanisms, effect, on the one hand, the recording of the products of the variable volume and pressures of steam—viz., the weights of the amounts of steam passing through the conduit as ordinates of a diagram; and, on the other hand, in the summing up of the said products on a counter of an integrator to obtain the weight of steam passing during any given period of time. As the scale for the diagrams of the recording mechanism there is assumed either a steam consumption in kilograms or pounds, per hour or per minute, and the unit of the counter of the integrator will also be one kilogram or one pound of steam, while the scale itself and the relation of the wheel gearing between the planimeter-wheel and the counter will in every case be selected to correspond with the results of the gauging of the measuring-piston.

The determination of the steam weights in the manner hereinbefore described is chiefly intended for measuring quantities of steam for heating purposes, which are not subject to continuously and suddenly increasing and decreasing variations in volume and pressure in the steam-pipes or conduits leading from the steam-generator to the place of consumption, as is the case in steam-conduits for steam-engines.

As well known, steam-engines receive the amounts of steam for the partial charges of the cylinder only intermittently, for which reason a measuring-valve inserted in the steam-conduit, and a multiplying, recording, and integrating mechanism connected therewith, would at every piston stroke of steam-engine be subjected to suddenly increasing and diminishing variations in volume and pressure, which the various mechanisms would not be able to follow up quickly enough by reason of their inertia.

Now, in view of the fact that the governor determines the variable amounts of admission to the cylinder of the steam-engine, the

governor is very suitable for use as an apparatus for measuring the volume of steam in place of the steam-measuring valve.

As shown in Fig. 303, the lever a^1 or the rod b^1, leading to the valve-gear of the adjusting mechanism, c^1, of the governor, is connected by the wire $e^1\ e^2$ by way of the guide-pulleys F^2 and F^3 with the multiplying, recording, and integrating mechanism.

Now, as is well known, the intervals between the movements of the lever a^1, connected to the adjusting mechanism c^1, are not proportional to the various amounts of admission to the engine cylinder; but it is necessary that the proportionality of the amounts of admission to the engine cylinder shall be transmitted to the recording and integrating apparatus. Therefore the wire $e^1\ e^2$, which passes otherwise directly over the guide-pulleys F^2 and F^3, is divided into two parts, of which the first part, e^1, is attached at one end to the governor lever, a^1, and at the other end, at g^1, to the periphery of a grooved cam F^1, while the part e^2 is attached at one end, at h^1, to the guide-pulley F^2, which is connected to the cam F^1, and at the other end to the slide-piece O, which guides the multiplying lever S. The cam F^1 is constructed in such a manner that when rotated through three-fourths of a revolution it will transmit the non-proportionate movements of the governor lever by means of the two wire arrangements in a proportional manner; that is to say, at equal intervals, corresponding to the amounts of admission to the engine cylinder, to the multiplier or to the recording and integrating apparatus.

The recording and integrating apparatus, together with the mechanisms appertaining thereto for determining the weights of steam-engines, is in principle and construction essentially the same as in the steam-meter for recording and integrating the weight of steam passing through pipe conduits, but with the modification that the pressure of the steam admitted to the cylinder is transmitted to the indicator I from the steam-engine by means of a steam-pipe, H^1, from the side valve-chest or from the steam-space between the steam cylinder and its steam-jacket.

In this mode of measuring the weight of steam it is more advantageous to determine the weight of steam admitted for each two strokes of the piston rather than the weight of the steam admitted during certain regular intervals of time, this being effected by replacing the clockwork of the recording drum and that for driving the plane disk i of the integrator by a common ratchet mechanism, which can be driven by a stroke or revolution counter, mounted on

the distributing shaft or on the flywheel shaft of the steam-engine. This ratchet mechanism is indicated in elevation in the integrator shown in Fig. 303, and consists of the ratchet-wheel r, lever s, pawl t, and wire c^3, which passes over one or more guide pulleys, F^4, to the operating lever of the stroke or revolution counter. The recording drum L of the recording apparatus is driven by wheel-gearing connected with the shaft of the disk i, said wheel-gearing not being shown in Fig. 303.

The operation of this steam-meter for steam-engines is analogous to that of the steam-meter for steam-conduits. When the steam-engine is at rest, the governor lever, a^1, is in the lowest position, corresponding to the greatest amount of admission to the cylinder; but the multiplying lever S is in the highest position shown in Fig. 303, the movable pivot, d, of the same being at zero pressure. Now as soon as steam is admitted to the engine the multiplying mechanism will move correspondingly to the pressure in the slide-valve chest or in the steam-jacket, as will also be the case with the pencil z and the planimeter-wheel k; but only after the engine has started will the variable admissions to the cylinder be registered and integrated, the weights of the amounts of steam entering the cylinder at every stroke of the piston being transmitted to the recording and integrating apparatus, as products of the volume of steam proportional to the amounts of admission and the pressure or density on one hand by means of the positions of the governor, and, on the other hand, by means of the indicator and the multiplying mechanism. The scale for the diagrams of the recording apparatus may be graduated, also, in this case, to a steam consumption in kilograms or in pounds per hour or per minute, the unit of the counting mechanism of the integrator being one kilogram or one pound, and the scale, as also the relations of the gearing between the planimeter-wheel and the counting mechanism, are determined for each steam-engine with reference to the piston area and piston-stroke, by calculation, and by gauging the steam consumption of the same at various admissions to the cylinder and various pressures of admission. The arrangement described with reference to Fig. 303, for the determination of the steam consumption of a steam-engine, can also be employed on substantially the same principle, and the same construction for the recording and integration of the average steam pressure in atmospheres, or of the work done by steam-engines in indicated and effective horse-power. Assuming that a steam-engine has a prompt governing action, that is to say, that the num-

ber of revolutions of the same can be assumed to be constant, then, in the case of varying loads, with reference to the work done by a steam-engine, the only variable factors in determining the work done are the so-called "mean" or "average" steam pressures corresponding to the admissions of the cylinder, because the numerical values of the piston area, the piston-stroke, and the number of revolutions of the engine can be taken as being constant. To every amount of work done by the steam-engine there corresponds, therefore, a certain average steam pressure, which, as is well known, can be calculated from a diagram taken from the engine by means of an indicator. This average steam pressure, however, can be found from a series of diagrams, according as the boiler pressure or admission pressure and the corresponding cylinder admission vary, the load remaining the same. The cylinder admissions are therefore directly dependent on the admission pressures, and every admission to the cylinder has a corresponding position of the governor. If, now, a series of indicator diagrams be taken from the steam-engine at varying loads and varying boiler pressures, and admission pressures, and the average steam pressures be calculated from the series of diagrams, and the corresponding positions of the governor and indicator be considered in connection therewith, that is to say, the corresponding positions of the governor at the various admission pressures be made into a scale, then for every engine a corresponding diagram can be made, according to which the transmission of the positions of the governor to the multiplying mechanism is arranged in such a manner that the variable amounts of work done by the engine are corrected proportionally by the simultaneous coöperation of the indicator I; that is to say, are transmitted at equal intervals to the recording and integrating apparatus.

DXXXVIII.*

ANHYDROUS AMMONIA GAS AS A MOTIVE POWER.

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THE burning question of the hour now is : "What power shall supplement or succeed steam and other forces" hitherto used by mankind, yet now found inadequate to meet the growing developments of science and civilization? This question, like Banquo's ghost, will not down, nor has the very useful broad utility of electricity settled the problem in a satisfactory manner, principally on account of its cost. Many bright people are endeavoring to discover a force which shall fulfil the conditions of tractability, safety and economy, as yet without success.

In some experiments upon ammonia as a motor fluid, recently conducted by myself, under the inventions of others, and by subsequent close study and investigation, I believe that the conditions above referred to have been more nearly fulfilled, than in any other process heretofore proposed for its use.

At the present time, nearly all the sal-ammoniac and other ammoniacal salts are prepared from the liquor which is obtained as a by-product in the manufacture of coal-gas. Coal consists of the remains of an ancient vegetable world, and contains about 2% of nitrogen, the greater part of which, in the process of the dry distillation of the coal carried on in the manufacture of gas, is obtained in the form of ammonia dissolved in the water and other products formed at the same time.

Recently W. F. Donkin has proved that ammonia can be synthetically prepared by the direct combination of its elements, the silent electric discharge being, for this purpose, passed through a mixture of nitrogen and hydrogen. It is also formed by the putrefaction or decay of the nitrogenous constituents of plants and animals; by the dry distillation of the same bodies; by heating these substances strongly, out of contact with the

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air; by the action of hydrogen on the salts of nitric or nitrous salts.

Ammonia gas has a density of .596 (air being 1.0); its volume is 983 times greater than the space occupied by its liquor, whilst steam under identical pressure occupies a space only 303 times greater than water. The latent heat of ammonia is about 552 , that of water being 990°. Ammoniacal gas is absorbed with avidity by water, one volume water at 80° Fahr. absorbing about 700 volumes of gas. The water becomes specifically lighter, while its volume is being augmented one-third. As the absorption of the gas goes on, the water becomes heated, and the latent heat of the gas reappears as sensible heat. It is in this property that water possesses, of absorbing such volumes of gas and of becoming heated whilst doing so, that the practicability of using this gas as a motive power rests; always bearing in mind that heat is the prime agency for producing gas. Ammoniacal gas can be liquified by pressure and frozen by a mixture of solid carbonic acid and ether in a vacuum. Its density is only about half that of atmospheric air. It is a strong base, and forms a great number of salts which are isomorphous with those of potassium and exhibit a close analogy to them. One of the most important of these salts is sal-ammoniac, NH_4Cl; largely used in dyeing, soldering and tinning. At present ammonium sulphate, $(NH_4)_2SO_4$, is the starting point for the manufacture of ammonium salts. It is used extensively as a fertilizer. The commercial article, *sal-volatile*, is a mixture of hydrogen-ammonium carbonate and ammonia carbonate. An ammoniacal salt is one formed by the union of ammonia with an acid, without the elimination of hydrogen, differing in this from metallic salts, which are formed by the substitution of the metal for the hydrogen of the acid.

Aqueous ammonia, solution of ammonia, spirits of hartshorn, or the combinations of ammonia with water, must also necessarily be understood for a full comprehension of our subject. Both water and ice absorb ammonia with great avidity, with considerable evolution of heat, and with great expansion. Davy found that one volume of water at a temperature of 10° C. and 29.8 inches barometric pressure absorbs 670 volumes of ammonia, or nearly half its weight; the specific gravity of this solution is 0.875. Aqueous ammonia is a colorless transparent liquid, smelling of ammonia, and having a sharp, burning, urinous taste.

Its specific gravity varies from 1.0 to 0.85, according to the amount of ammonia contained. Its boiling point varies, according to the percentage of ammonia and its specific weight. At a specific gravity of 0.85 and 35.3% ammonia, its boiling point is $-4°$ to $+92°$ when its specific gravity is 0.99, and its percentage of ammonia is 2.0. A perfectly saturated solution freezes between $-38°$ and $-40°$ C., forming shining flexible needles. At $-49°$C. it solidifies to a gray gelatinous mass, almost odorless. It loses almost all its ammonia at a temperature below 100° C. Aqueous ammonia possesses the property of dissolving many salts which are not soluble in water, chromic and stannic oxides, the protoxides of tin, cadmium, and zinc, the oxides of copper and silver; these combinations are decomposed by heat, losing ammonia.

In order to determine the percentage of ammonia in any given solution of what is commonly known as "commercial ammonia," I have found the following table of great value and practically correct; it rests on the temperature of the solution.

$\frac{1}{16}°$	Beaume	= 0.117	per cent.	ammonia.	17°	Beaume	= 13.12	per cent.	ammonia.
$\frac{1}{8}°$	"	0.234	"	"	18°	"	15.0	"	"
$\frac{1}{4}°$	"	0.468	"	"	19°	"	16.87	"	"
$\frac{1}{2}°$	"	0.931	"	"	20°	"	18.75	"	"
11°	"	1.87	"	"	21°	"	20.62	"	"
12°	"	3.75	"	"	22°	"	22.5	"	"
13°	"	5.62	"	"	23	"	24.37	"	"
14°	"	7 5	"	"	24°	"	26.25	"	"
15°	"	9.37	"	"	25°	"	28.12	"	"
16°	"	11.25	"	"	26°	"	30.00	"	"

The initial temperature of steam at 150 lbs. pressure is 446° Fahr. Anhydrous ammonia gas at the same pressure has a temperature of 80°.

The relative proportions of the two are:

Water.	Ammonia
Latent Heat, 990	552
Relative Volume, 1,728	.1313.28
Boiling Point, 212° Fahr.	$-38.5°$ Fahr.
Ratio, 100	.76

The temperature and pressure exerted by ammonia gas are founded on the relative points as ascertained in practice; that at a temperature of 60° Fahr., there is exerted a pressure of 110 lbs., and at 80° Fahr., a pressure of 10 atmospheres, or 147 lbs. The proportion being, $20 : 37 :: 1° : x$.

The following pressure table is made up from actual practice, and may be regarded as substantially correct:

A temperature of	50°	Fahr.	exerts a pressure of	92.5	pounds.	
"	51°	"	"	94.35	"	
"	52°	"	"	96.2	"	
"	53°	"	"	98.05	"	
"	54°	"	"	99.9	"	
"	55°	"	"	101.75	"	
"	56°	"	"	103.6	"	
"	57°	"	"	105.45	"	
"	58°	"	"	107.3	"	
"	59°	"	"	109.15	"	
"	60°	"	"	110.0	"	
"	61°	"	"	112.85	"	
"	62°	"	"	114.7	"	
"	63°	"	"	116.55	"	
"	64°	"	"	118.4	"	
"	65°	"	"	120.25	"	
"	66°	"	"	122.1	"	
"	67°	"	"	123.95	"	
"	68°	"	"	125.8	"	
"	69°	"	"	127.65	"	
"	70°	"	"	129.5	"	
"	71°	"	"	131.35	"	
"	72°	"	"	133.2	"	
"	73°	"	"	135.05	"	
"	74°	"	"	136.9	"	
"	75°	"	"	138.75	"	
"	76°	"	"	140.6	"	
"	77°	"	"	142.45	"	
"	78°	"	"	144.3	"	
"	79°	"	"	146.15	"	
"	80°	"	"	147.0	"	
"	81°	"	"	149.85	"	
"	82°	"	"	151.7	"	
"	83°	"	"	153.55	"	
"	84°	"	"	156.4	"	
"	85°	"	"	157.25	"	
"	86°	"	"	159.1	"	
"	87°	"	"	160.95	"	
"	88°	"	"	162.8	"	
"	89°	"	"	164.65	"	
"	90°	"	"	166.5	"	

If smaller or greater pressures are required than those given in the table, it becomes simply a question of lowering or raising the temperature.

Anhydrous ammonia, or *dry ammonia* gas, condenses to a

liquid at $-38\frac{1}{2}^{\circ}$ Fahr., or it can be condensed by a pressure varying from 150 to 185 lbs. at a temperature of $+70^{\circ}$ Fahr. On the removal of this pressure, the gas expands fully. This is not entirely availed of in the ammonia motor, as during its expansion it is used like steam to drive the piston of an engine. The gas is as easily handled as steam, quite as safe, far cheaper, and in many respects resembles steam.

There have been a great number of engines invented and patented, using ammonia gas alone, or in combination with other vapors, as a motive force. Such motors have been invented by Gamjee, Seyforth, Jean Foot, Lamback, Dr. Emile Lamm, and many others, who, with two or three exceptions, have gone about the work in hand as patenters and copyists, and not as true inventors. At any rate, the patent offices are full of their claims. Enough has been accomplished, however, to demonstrate that the ammonia engine is a practical success, and no longer a theory and an experiment; and, further, that ammonia gas alone, and not combined with other vapors, is the true solution of this subject. Such motors have been run under the most severe conditions, and have proved an unqualified success in every way; and were it not for the greed and unscrupulous tactics of certain people, there would be several lines of ammonia cars and locomotives in operation.

The ammonia locomotive is not perfect to-day, nor is our older friend, propelled by steam, but it will be very soon.

I wish, before describing the newest motors and plants, to draw attention to the older machines.

M. Fromont's ammoniacal engine was exhibited at the Paris, Exposition of 1868. His motive power was a vapor containing 80% ammonia and 20% steam, which latter was, as you will learn later, directly contrary to the present method, where the endeavor is to obtain as dry a gas as possible, and thereby a perfectly pure anhydrous ammonia liquid. Fromont's engine, however, demonstrated one thing, viz.: its economy, as it consumed only one-quarter as much fuel as a steam-engine of like power and under the same conditions.

Gamjee's engine, called the "Zeromotor," was intended to use ammonia gas as the power agent. It was a thermodynamic engine, and one with a closed circuit, with a liquid boiling at a low temperature, relatively to water transformed into vapor, the molecular energy of which is converted into the mass or molar

motion of the piston, so that its initial condition is restored. In this manner, in a heat-engine, the temperature is extended within which the heat is utilized downward, in the direction of the absolute zero, instead of upward, above the temperature of surrounding objects.

The first law of thermodynamics is: "Heat and mechanical energy are mutually convertible in a certain ratio."

The second law: "It is impossible for a self-acting engine, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of surrounding objects."

Clausius, who first clearly defined Carnot's principle, says: "It is impossible for a self-acting engine, unaided by any external agency, to convert heat from one body to another body at a higher temperature."

I refer to these thermodynamic laws here, as they bear directly on the principles of the ammonia-engine as now worked out. The invariable principle, that the same cause (under the same circumstances) produces the same result, is applicable to both steam and ammonia (the law of Mariotte), which is invariably the same, viz.: that "all gases or vapors expand equally by the same degree of heat added to their specific heat." However, ammonia is slightly an exception to this, and greatly in its favor.

Gamjee made the following statements. "Anhydrous ammonia at 0° C. has a vapor tension of 3,183.34 mm., or about four atmospheres. At 10° it reaches 4,574.03 mm., or six atmospheres. At 20° the pressure is 6,387.78 mm., or nine atmospheres. At 30° (tropical heat) it is over 8,000, or 10½ atmospheres. Since at blood heat 200 lbs. to the square inch is available, it is evident that the usual temperature of ocean or river water is most desirable in practice, and best when below 20° C. The latent heat of ammonia is used in developing energy so as to reduce the amount of rejected heat to a minimum, and to obtain a maximum of liquefaction." Gamjee's engine was a double cylinder rotary engine.

It is the remarkable affinity of ammoniacal gas for water, by which it is able, at any time after its condensation into a liquid, to reproduce, at a distance from where it was condensed, *a force equal to the heat which was necessary for its condensation*, which makes the ammonia gas-engine a possibility.

The most important of the older engines was that of Dr. Emile Lamm; later ones, in their principles, following his closely. In 1870, in describing his engine, he said: "This reproduction is owing to the fact that the latent heat of the gas appears anew in water of reabsorption, and is retransferred to the liquified gas. This takes place through metallic tubes of which the reservoir is composed, from the water of reabsorption which surrounds them, and is similar in its operation to the action of fire in the furnace of a steam-boiler."

Lately we have vastly increased the number and dimensions of these tubes over those thought sufficient by Dr. Lamm, because, although we find that a small evaporation surface would demonstrate the utility, yet for practicable purposes a large evaporating or heating surface was necessary. At a single step I increased this surface for 1 H. P. from five to thirty square feet, and find it economical in many ways.

By reference to Fig. 308, which is Dr. Lamm's engine, the arrangement just spoken of will be easily understood. *cc* is the ammonia reservoir filled with the anhydrous liquid to the line *dd*. *AA* is the tank filled with weak ammoniacal water to the line *aa*. *C* is the pressure-pipe leading to the engine *EE*. *D* is the exhaust-pipe leading from the engine to the water in the bottom of the tank *AA*. When, by means of the throttle-valve *x*, the gas in the reservoir *B* is permitted to act on the piston of the engine, through the pressure-pipe *C*, the engine begins to work with a force equal to 150 lbs. to the square inch, at a temperature of 90° Fahr., consequently the whole apparatus must remain at a temperature of 90° Fahr. to give an effective pressure of 10 atmospheres for any given time that may be desired.

One of Dr. Lamm's engines, propelling a street car on a seven-mile run, was equal to 2 H. P.; the liquid ammonia expended was 1.16 cubic feet. Therefore, the latent heat of ammonia gas (according to Dr. Lamm) being 880, the whole heat expended during the trip made was sufficient to raise 84 gallons of water from a temperature of 83° to the boiling point, 212°.

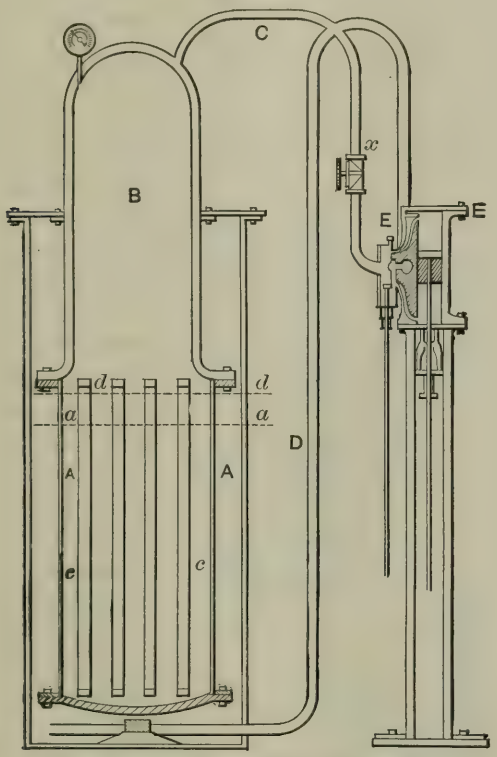
I will now proceed to discuss and describe the ammonia manufacturing plant and the ammonia engines as they are now, in the light of the latest improvements.

The chief difficulty with all plants for the manufacture of anhydrous ammonia liquid has heretofore been, that the gas which it has been sought to condense, contained more or less

aqueous vapor, which, remaining with and being condensed with the gas, resulted in a liquid not absolutely pure, and robbed it of its power to some extent.

In Fig. 309 is shown a design, an improvement on one actually in operation, which meets this difficulty in a most satisfactory way. I will say in advance of describing the plant, that it is

FIG. 308.



DR. LAMM'S AMMONIA ENGINE

absolutely necessary that all parts of such a plant shall be so constructed as to withstand in *all its parts* a pressure of at least 200 lbs. to the square inch.

A is a solution boiler, or still, similar in construction to an ordinary tubular boiler, so set that the end next the stack *s* is slightly lower than the other. The grate is at *G*, and the heat passes first beneath the boiler, thence back through the tubes, and out at the stack. No great heat is required, 122° Fahr.

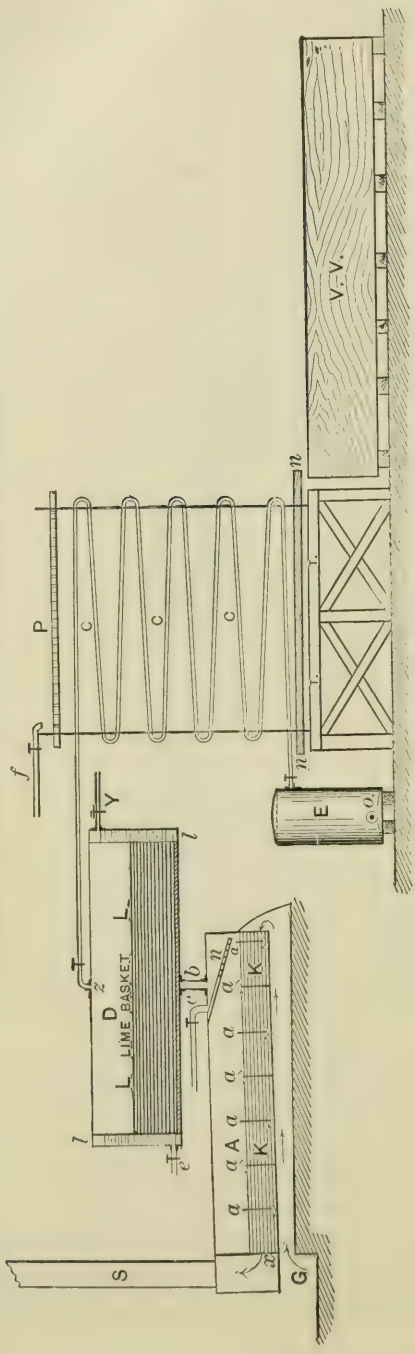


FIG. 309.

sufficing. The ordinary commercial ammonia is introduced at *c*, and falls on the scattering plate *p*, and from thence on the tubes *kk*. You will observe a number of upright partitions *aaa*, and you will also notice that the first one is raised just above the bottom of the boiler, the next one being all the way down, the next above, and so on. These partitions are merely thin sheets of boiler iron, through which the tubes pass, their object being, in connection with the sloping setting of the boiler, to force the ammonia solution to follow the course indicated by the arrows, in order that it may, by means of the heat, become thoroughly deammoniaized. This latter operation begins immediately when the solution commences to fall on the tubes through the scattering plate, and it is so thoroughly effected, that by the time it reaches the blow-off point at *x*, it contains usually not over 5% ammonia. The gas, as it evaporates, rises from the boiler, through the scattering plate and the

inpouring solution, to and through *b*, into what is called a dehydrator *D*. The gas is accompanied by aqueous vapor, and the object of the dehydrator is to free it from this. The dehydrator is a long cylinder, having at either end a water compartment *ll* connected with a series of tubes. On the bottom of the cylinder is an angle-shaped perforated plate; the gas rising from the boiler meets this perforated plate, which scatters it all along and around the tubes, through which cool water let in at *Y*, and passing off at *E*, is constantly flowing. Just above the tubes is a wire-basket *ZZ*, filled with lime, the pieces being about the size of peas: the partially dehydrated gas, from contact with the cool tubes, now passes through the bed of lime, which is about two inches thick, and is there freed of its watery vapors, and becomes fully dry. By this means one obtains in the upper, or storage, part of the dehydrator, a perfectly dry gas, which, passing out of the top at *Z*, flows to the coils *ccc*, where it is condensed, and falls by means of gravity and the pressure from the still (150 lbs.) behind it into the storage tank *E*. There are ten rows of condensing coils, only one of which is shown in the figure; each row has a total length of 100 feet. The condensation is accomplished by means of very cold water falling from the scattering table *P* over the coils. In order that this water may not be wasted, it is caught in a tray *nn* below, and conducted to a series of wooden vats *VV*, where it is allowed to cool, and used over and over again; it can also be artificially cooled in the same manner as is done in the cold storage plants.

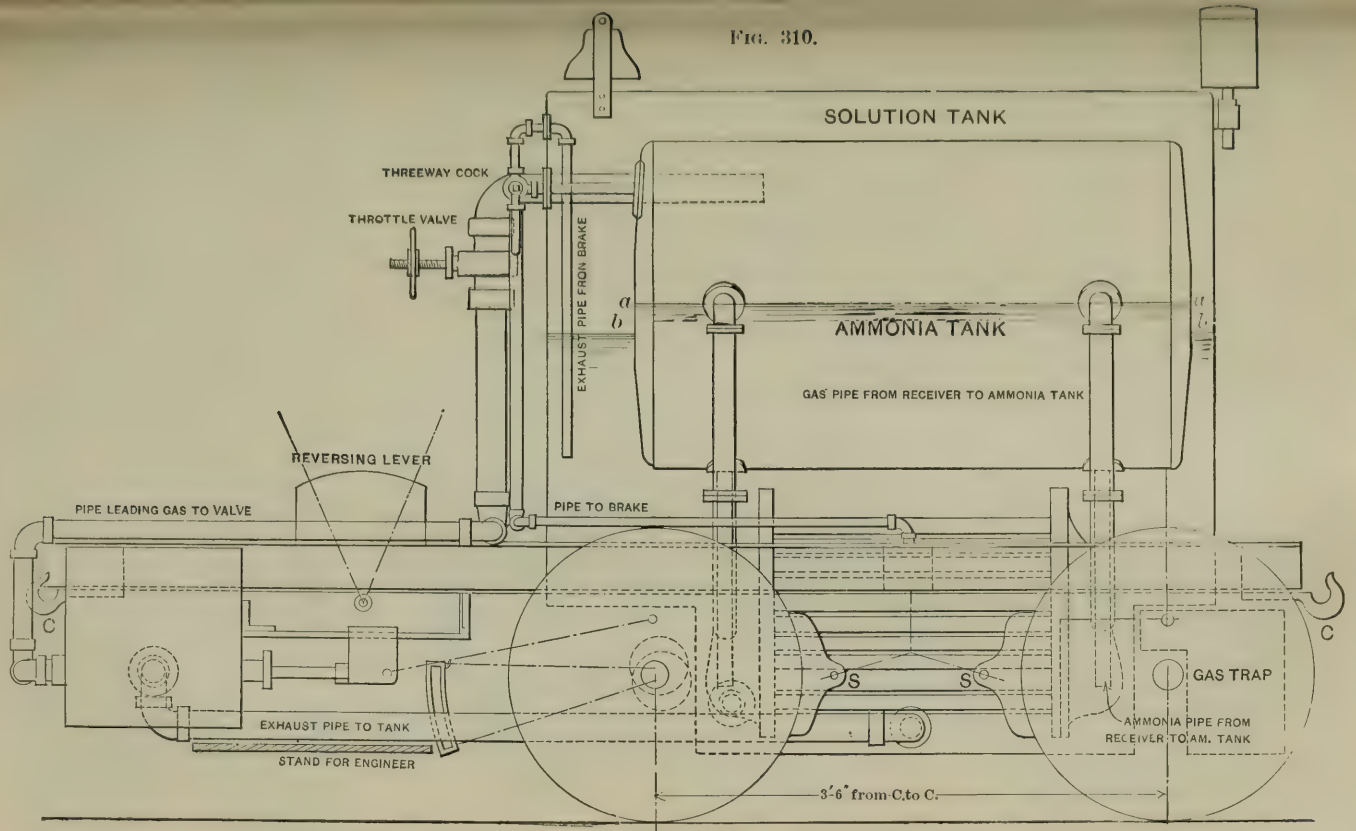
The illustrations shown in Figs. 310 to 313 are of an ammonia locomotive recently designed for transfer purposes, intended to be used on a cable road for shifting the cars on and off of the cable, into or out of the car shed. The house space of the company being limited, their engineers arranged an electric travelling table, and on this a turn-table; the latter was, of course, quite limited in length, only long enough to allow of a 36-foot car and a motor 10 feet over all. In addition to this, the company's engineer imposed, on account of balance of the table, that the total weight, with charge, of the motor, should not exceed 3 tons, and at the same time should have a traction force of 1,000 lbs.; total height above rail, 10 feet; speed, not less than 6 miles per hour, and this speed to be attained in six seconds. Further, the shifter must be able to run a reasonable length of time without recharg-

ing. The annexed drawings illustrate the design made to fill these specifications. I have made some slight changes from the original designs, notably in placing the gas-trap forward of the front axle, instead of just behind the rear axle, and have obtained thereby a more perfect distribution of weight. I have also largely increased the amount of evaporating surface, by doubling the number of the tubes, adding thereby to the quickness of evaporation and the pressure. Its power is vastly increased, as is its speed, by these changes, without overstepping the limits of weight, etc., imposed.

The locomotive shifter is direct acting. I have endeavored in the drawings to make everything so plain that description would be largely avoided. The inner or anhydrous ammonia liquid tank, of $\frac{3}{8}$-inch boiler iron, is to contain the charge, in this case calculated amply for a 14-mile run. This charge fills the tank half full, the upper half serving as a gas reservoir. Below this tank is hung the evaporator, manifolded at either end. The evaporator and the ammonia tank are enclosed in one large outer, or solution, tank, which is partially filled with water, or the blow-off solution from the still (containing about 5% ammonia) to the line *bb*. The engine cylinders are placed on the frame at the rear end of the locomotive. The outer tank is made in three sections (no great pressure is possible in it) on account of cheapness of construction, and it also allows of the raising off of the upper rounded section, or the intermediate, to examine or repair the inner tank, evaporator, or piping. The frame consists of two 4-inch channel irons (20 lbs. per yard) 9 feet long, which support the outer tank by means of cast-iron suspenders bolted to the frame; the jaws for the axle journal and the cylinders are also bolted to the frame. It is supported by equalizers connected by means of springs. The frame is 20 inches above the rail, with its full load.

The machinery consists of two 6 x 9 inch cylinders, with piston valves, surrounded by cast iron jackets, the initial power behind the piston being 4,240 lbs. The piston works on a crosshead which is connected with the connecting rod to the driving wheel, and thence by means of a link rod to the front wheel. The piston valves are inside, and their rods are connected by means of rockshafts and levers with the reversing link, which latter are also inside. The brakes, worked by gas also, led through a three way cock or brake valve, to a 3-inch cylinder, the

Fig. 310.

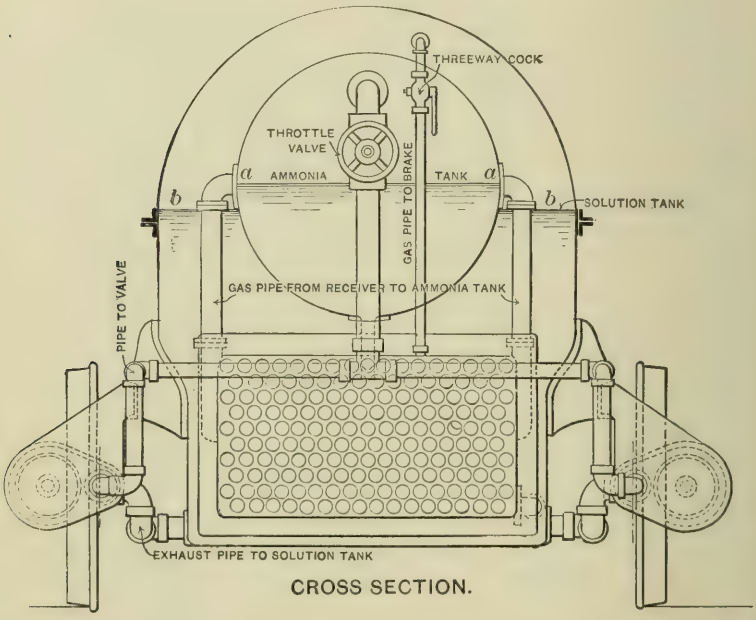


SIDE ELEVATION.

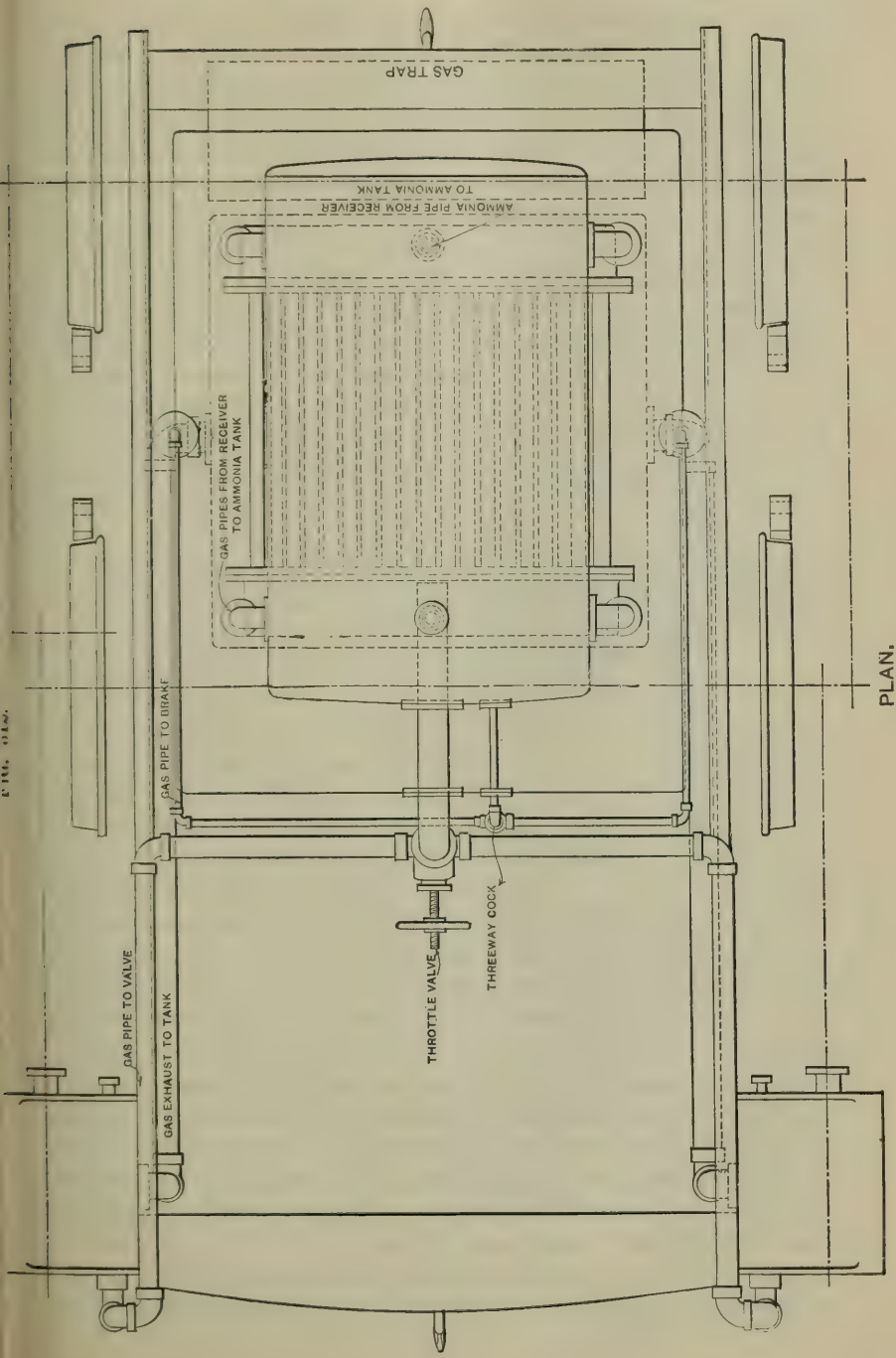
piston of which works on the brake arms, and these on the shoes. When the gas is on, and it is desired to cut off the brakes, the gas returns through the valve to the solution tank, where it is at once absorbed. The brake shoes are hung in such a manner that they loosen when the gas is cut off. The gas trap is hung in front of the forward axle, is of $\frac{1}{8}$-inch boiler iron, air and water tight.

The manner of operating the locomotive is as follows. The inner tank receives its charge, and the outer tank at the same

Fig. 311.

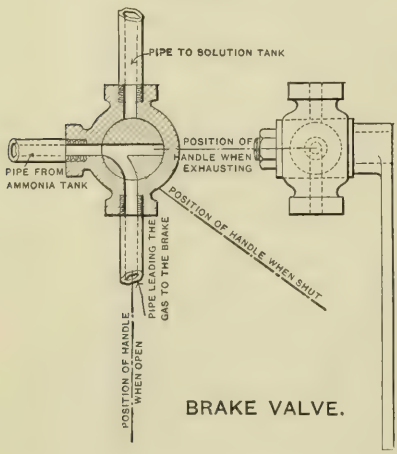


time is filled with the 5 – 7% blow-off solution from the still, this solution being charged usually at a temperature of 80° Fahr., though a little more or less temperature does not matter: if above 80 it will give increased pressure; if below, it will increase its heat in running by the discharge from the cylinders. The motor is now ready to run; when its charges are exhausted, it returns to the station and they are renewed. The quantity of absorbing fluid in proportion to the anhydrous liquid charge is about 5 to 1. When the liquid has been exhausted it has been in the form of exhaust gas absorbed into the solution in the


GAS TRAP
AMMONIA PIPE FROM RECEIVER TO AMMONIA TANK
GAS PIPES FROM RECEIVER TO AMMONIA TANK
GAS PIPE TO BRAKE
GAS PIPE TO VALVE
GAS EXHAUST TO TANK
THROTTLE VALVE
THREEWAY COCK
PLAN.

outer tank, which latter has practically become commercial ammonia, which, being withdrawn at the station, is redistilled and used over and over again, a new charge taking its place in the motor, as well as a new charge of anhydrous liquid. Thus the process repeats itself almost indefinitely, the annual loss being not over 10%; from commercial ammonia to anhydrous ammonia gas, to anhydrous liquid, to gas, in this form used as a motive power, discharged then into water, which it converts into commercial ammonia. There is no reason why pure water should not be used, instead of the weak solution of ammonia from the blow-off, for absorbing; this is, in fact, done, but the objects in using the blow-off solution from the still are obvious: first, the small percentage of ammonia therein is saved; and, secondly, the temperature necessary for charging for proper operation could not be more economically or easily obtained.

Fig. 313.


PIPE TO SOLUTION TANK
POSITION OF HANDLE WHEN EXHAUSTING
PIPE FROM AMMONIA TANK
POSITION OF HANDLE WHEN SHUT
PIPE LEADING THE GAS TO THE BRAKE
POSITION OF HANDLE WHEN OPEN
BRAKE VALVE.

The economy of such a motor is easily understood: practically no loss of material, small amount of fuel consumed in the manufacture, the absence of a stoker on the motor, it requiring but one man to run it.

The exact cost of manufacturing anhydrous ammonia liquid has not yet been ascertained, nor the cost of operating; this will only come with time and experiment, but sufficient is known to state positively that the cost is not over one fourth that of steam or any other motive force.

To revert again to the locomotive, the liquid force is as follows: it passes down from the inner tank into the evaporating tubes, and these, surrounded by the 80° Fahr. solution, cause it to rapidly evaporate at a pressure of 147 lbs. to the square inch. It rises from the manifolds at the ends of the tubes to the upper half of the inner tank, from whence it flows to operate the engines. The gas exhausted from the engine cylinders passes in at the bottom of the outer tank, at a point between the axles,

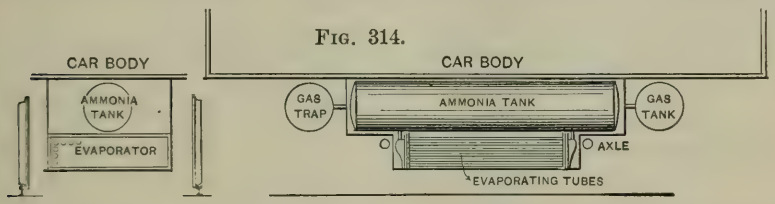
and is instantly absorbed. A small pipe, leading from the gas reservoir, passes through the three way cock to the brake cylinder, and by simple means is returned into the solution of the outer tank.

The engine cylinders are surrounded by jackets, through which absorbing solution flows, for a two-fold reason; namely, to keep up an equitable expansion temperature, and to absorb any gas leakage that should occur.

The object attained by the gas trap, which is about half full of water, which it is seldom necessary to renew, is to absorb through a check valve, by which it is connected with the outer tank, any gas not absorbed therein, avoiding thereby any possible back-pressure, smell, or leakage.

The discharge of the exhaust gas into the solution of the outer tank keeps the temperature of this solution almost constantly at 80° Fahr., for reasons already given, the exception being that

Fig. 314.



this discharge usually raises the temperature; the proof of which I have found to be, that a motor returning from a trip usually does so with its gauge showing a higher pressure than that with which it started out. Against this I find, that if from any cause an ammonia motor is allowed to stand, say on a siding all night, the temperature of the absorbing solution will fall materially. A simple means of raising its temperature, and the pressure as well, is to allow a small jet of ammonia gas from the reservoir to flow into the absorbing solution, which quickly heats it.

Fig. 314 represents a recent plan of mine for placing the motor and machinery beneath the platform of an ordinary street-car. Similar, but very cumbersome, apparatus has already been placed in this way, and it had various inconveniences which this arrangement obviates. This motor, which could be attached to any car without altering its body, has the following characteristics:

Capacity of solution tank.....600 gallons
Capacity of ammonia tank.....90 gallons

Heating surface of tubes.....200 square feet
Capacity of gas tank.....40 gallons
Capacity of gas trap.....40 gallons
Centre to centre of axles.....6 feet
Solution tank is 8 feet by 2 feet 6 inches by 3 feet 6 inches.
Ammonia tank is 7 feet 6 inches by 17 inches.
Diameter of wheels, 30 inches.
Bottom of tank above the rail, 6 inches.
Car body, 16 feet without platforms.

The cost of such a motor placed beneath ordinary street-cars would be in the neighborhood of $600.

DISCUSSION.

Mr. Kent.—I do not see in the paper any statements of the economical performance of the gas engine. I hope when the paper is finally published that we shall have that information stated in it. It ought to have appeared in the paper, so that we might discuss it.

*T. W. M. Draper.**—Under the question of cost of operation the latest inventions conclusively prove that it is very small. The ammonia of commerce, consisting of about 30% ammonia and 70% water, is sold at 5½ cents per pound, there being about 8 lbs. to the gallon; and, as this is not lost (excepting about 10% per annum), but is used over and over, this should be estimated in the first cost of the plant, and not in the operating. As the basis of cost of operation by actual running, I will take the tests made on an ammonia motor car, stating, however, that the price of the coal used was $5.75 per ton—much higher than would be the cost ordinarily. The motor was on an ordinary street car; the track used was a new and very rough one. The amount of coal and cost of ammonia are figured from two test runs, made December 11, 1891, and February 15, 1892. The majority of the runs were made in cold weather, and, in all, the pressure on the gauge was greater after making the run than at the start.

* Author's Closure under the Rules.

TESTS OF FUEL CONSUMPTION OF AN AMMONIA CAR.

Date.	Temp. atmos., degs. F.	Pressure of gas.	Miles run.	Gals. anhyd. used.	Lbs. of coal.	No. gal. per mile.	Cost per mile, cents.
1891.							
December 8	35	140	5	26	36.00	5.2	1.48
" 12	40	190	8	35	42.00	4.37	1.25
" 16	30	160	9	43	51.6	4.77	1.31
" 19	20	190	10	46	55.2	4.6	1.30
" 29	10	160	12	57	68.4	4.75	1.35
1892.							
February 9	4	180	8	36	43.2	4.5	1.28
March 13	25	160	14	53	63.6	3.78	1.07
" 16	10	160	18	57	47.2	3.19	0.937
" 19	33	110	17	54	44.5	3.18	0.797
" 22	36	160	6	20	16.50	3.33	0.833
" 27	30	170	8	24	21.00	3.00	0.75
" 15	25	180	10	31	27.8	3.1	0.775
" 21	28	160	12	35	28.8	2.91	0.727
" 26	37	180	14	40	35.00	2.85	0.712
April 9	20	170	8	27	22.14	3.37	0.83
" 16	50	180	6	21	17.22	3.5	0.875
" 21	42	175	8	28	22.96	3.5	0.875

It is very difficult to obtain accurate figures as to cost per mile of operating various systems now in use. A careful comparison of the electric trolley, cable, and horse-car systems, which is approximately correct, shows :

Horse-car	21.25	cents	per	mile.
Cable	14.12	"	"	"
Electric trolley	13.25	"	"	"
Ammonia gas	7.68	"	"	"

With the improvements now made on the ammonia motor, especially in the absolute tightness of the liquid and gas receivers, the cost per mile of 0.875 cents can be guaranteed as the average.

DXXXIX.*

A GENERAL ENGINEERING CLASSIFICATION AND INDEX.

BY WM. L. CHASE, WORCESTER, MASS.

Some Possibilities in the Extension and Use, by the Engineering Professions, of the Dewey Decimal System.

I have long had a growing impression that great service could be rendered by some general and uniform system of classifying, for preservation and reference, notes, memoranda, clippings, trade catalogues, books, periodical articles, etc. This feeling has been largely fostered by Mr. Melvil Dewey's "Decimal Classification and Relative Index," published by the Library Bureau, Boston. A short time ago, in order to discover whether my leading impression and Mr. Dewey's book had conspired to unbalance me on the subject, or whether there is an actual need of something in this line, I sent to a number of the members of this Society, and to a few other gentlemen, a circular letter soliciting what I thought would be fairly representative opinions. While the result as to the main issue in sending out the circular is perhaps still in doubt, I have been stimulated to present the question to this larger audience, satisfied that it will at least promote a healthful discussion of the need, and that, through this organization, if at all, may be supplied whatever need exists.

It was made evident by the responses to my circular that it will be necessary to give here a brief description of the Dewey system, which was developed chiefly in the interest of library economy, and in which the whole field of knowledge is arbitrarily divided into nine classes, represented by the Arabic numerals in hundreds place, namely:

Philosophy, 100.; Religion, 200.; Sociology, 300.; Philology, 400.; Natural Science, 500.; Useful Arts, 600.; Fine Arts, 700.; Literature, 800.; History, 900.; Cyclopædias, Periodicals, etc., too general in character to fit any of these classes, make a

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

tenth class, marked 000. Each class is divided into nine or less divisions, and each division into nine or less sections, represented respectively by the numerals in tens and units places. Subdivision is further carried out decimally to such an extent as may be necessary to define any desired minute classification of a subject. Naught in each place, division, section, etc., holds its normal power, and signifies that the material so marked is too general to be subdivided. Mr. Dewey's classification tables occupy in his fourth edition 360 $6\frac{1}{2}'' \times 9\frac{1}{2}''$ pages. Supplementing the tables are 186 pages devoted to a relative subject index, which contains more than 20,000 alphabetically arranged references to the heads, subheads, etc., contained in the tables, including synonymous and alternative names, catch titles, etc., with the classification number of each, giving its exact place in the tables.

To index and file an item, it is marked with its classification number and placed in the numerical order thus indicated in the collection which it joins. To find an item, the subject index is consulted for the classification mark, which gives the numerical place in the collection of all the items the collection contains under the head sought. The items under each head may be arranged alphabetically by authors or titles, and, if the collection is large enough to require it, the items may be alphabetically indexed under any head, though generally the items themselves, properly arranged, furnish their own index.

Notwithstanding the generous proportions to which the latest edition of Mr. Dewey's book has brought his work, it must be changed in some headings under engineering and greatly extended to fit it for general use. In a limited way I have attempted to expand some of Mr. Dewey's tables under that subject for my own use. In doing this I have come more and more to believe in the possible usefulness of the scheme, in some degree, to all concerned. The degree of that usefulness depends upon the amount and character of the interest which can be brought to the support of the work of perfecting the tables. It is my purpose at this time to invite discussion of the advisability of undertaking, through a competent committee or otherwise, to make a general classification of engineering by experts in the several departments. With this object in view I shall present, first, in illustration of the Dewey plan, the divisions under the sixth class, Useful Arts; the sections under the second or

engineering division of that class, and some of the decimal subdivisions of the first or mechanical engineering section of that division: and second, in illustration of what I have attempted to do in extending Mr. Dewey's work, the corresponding decimal subdivisions of my extended tables, with the relative subject index covering the same. Following these I shall endeavor to point out some of the merits of the system and some of the ends that it seems to me can be served by extending it.

The following heads are given as they stand in Mr. Dewey's fourth edition:

600. Useful Arts.

601. Philosophy. Theories, etc.
602. Compends. Outlines.
603. Dictionaries. Cyclopedias.
604. Essays. Lectures. Addresses.
605. Periodicals. Magazines. Reviews.
606. Societies. Fairs. Exhibitions.
607. Education. Schools of Technology.
Divided Geographically like History Tables.
608. Patents. Inventions.
609. History of Useful Arts in General.
610. Medicine.
620. Engineering.

.01, Statistics; .02, Quantities and Cost; .03, Contracts and Specifications; .04, Designs and Drawings; .05, Executive; .06, Working and Maintenance; .07, Laws; .08, Patents; .09, Reports.

.1, Strength of Materials; .2, Compends; .3, Dictionaries, Cyclopedias; .4, Essays; .5, Periodicals; .6, Societies; .7, Study and Teaching; .8, Tables and Calculations; .9, History of Engineering.

621. Mechanical Engineering.

.1 Steam Engineering. (*See* 536.81.)

.11 Mechanism of Steam Engine.
.12 Marine Engines and Ship Propulsion. (*See* 699.)
.13 Locomotive Engines.
.14 Traction Engines.
.15 Portable Engines.
.16 Stationary Engines.
.17
.18 Steam Generation. Boilers. Furnaces.
.19 Steam Heating. (*See* 697, 536.83, 628.8, 644.)

.2 Water Engines or Motors.

.21 Water Wheels. (*See* 532.84.)
.22 Overshot and Breast Wheels.
.23 Undershot Wheels.
.24 Turbines.
.25 Water Pressure Engines. (*See* 532.82.)
.26 Hydraulic Presses. (*See* 532.81.)
.27 Hydraulic Ram. (*See* 532.83.)
.28
.29 Mill Dams, Sluices, etc. (*See* 627.8.)

.4 Air and Gas Engines and Other Motors.

.41 Caloric Engines.
.42 Compressed Air Engines.
.43 Ignited Gas Engines. (*See* 536.82.)
.44 Binary Vapor Engines.
.45 Windmills.
.46 Animal Motors. Tread Mills.
.47 Solar Engines.

.5 Air Compressors. Ice Machines.

.6 Blowing and Pumping Engines.

.61 Piston Blowers.
.62 Rotary Blowers. Fans.
.63 Centrifugal Blowers.
.64 Steam Pumps and Pumping Engines.
.65 Piston Pumps.
.66 Rotary Pumps.
.67 Centrifugal Pumps.
.68 Fire Engines. (*See* 352.3, Fire Department ; 614.84, Fires.)

622. Mining Engineering.
623. Military and Naval Engineering.
624. Bridges and Roofs.
625. Railroad and Road Engineering.
626. Canal Engineering.
627. River, Harbor, and General Hydraulic Engineering.
628. Sanitary Engineering.
629. Other Branches of Engineering.
630. Agriculture.
640. Domestic Economy, Hotels, Flats.
650. Communication. Commerce.
660. Chemical Technology.
669. Metallurgy and Assaying.
670. Manufactures.

680. Mechanic Trades.
690. Building.

The following examples are taken from my draught of the extended tables, in which, to avoid confliction with the published signification of the decimals, I have employed the letter E to represent Mechanical Engineering, instead of Mr. Dewey's number 621.

E .1 Steam Engineering.

.11 Theory and general practice.
.111 Steam economy.
.1111 Systems, Instruments and Records of measurements and tests of engines and boilers.
.1112 Expansion, Superheating, Jacketing, Cylinder condensation, etc.
Simple, Compound, and Multi-cylinder efficiency.
High pressure efficiency.
.1113 Boiler economy.
Feed-water heaters, Filters, Purifiers, Fuel economizers.
Back pressure relieving and feed-water heating apparatus.
Exhaust steam purifiers, Oil separators, etc.
Boiler and tube cleaners.
Life, deterioration, etc., Corrosion, Incrustation, Scale.
.1114 Steam *vs.* Water power.
.112 Dangers, Accidents, Engine failures, Boiler explosions.
.119 Lubricators, Revolution counters and registers.
.12 Marine steam engineering.
Steamship propulsion.
Paddle, screw, hydraulic.
Marine engines.
Paddle, screw.
Simple, compound, triple, etc., cylinder.
Non-condensing, condensing. (Surface ; jet.)
.13 Steam locomotive engineering.
Locomotive engines.
Traction and portable engines.
Steam road machines, rollers, etc.
.15 Steam blowing, compressing, and pumping machinery.
.152 Blowing engines.
.153 Steam air compressors and Refrigerating machinery.
.154 Steam fire engines and pumps.
Portable, installed.
Direct piston engines and pumps.
Piston engines and rotary pumps.
.155 Steam water works and sewage pumping engines.
Direct piston.
Direct crank.
Crank and beam.

Simple, compound, triple, etc., cylinder.
Non-condensing, condensing. (Surface ; jet.)
.156 General steam pumping machinery.
.1561 Boiler feed, Tank, and Pressure pumps, Injectors, etc.
.1562 Vacuum and Circulating pumps, Sugar pumps.
Condensing apparatus pumps.
.1563 Mining, Wrecking, Sinking, and Deep well pumps.
.16 Stationary steam engineering.
.162 Plain slide valve engines.
Horizontal, vertical.
.163 Automatic shaft governor engines.
Horizontal, vertical.
Simple, compound, triple, etc., cylinder.
Non-condensing, condensing. (Surface ; jet.)
.164 Releasing valve gear engines (Corliss type).
Horizontal, vertical.
Simple, compound, triple, etc., cylinder.
Non-condensing, condensing. (Surface ; jet.)
.165 Single acting double cylinder engines.
Vertical.
Simple and compound cylinder.
Non-condensing, condensing. (Surface ; jet.)
.166 Steam turbines, Rotary engines, etc.
.167 Special direct connected steam engines and machinery.
Rolling mill engines.
Steam dynamos.
Hoisting, conveying, and elevator engines.
(*See* Ropeways, Hoisting machinery, etc., E .86.)
Steam shovels and dredges.
Steam hammers. (*See* Forging, E .95.)
.18 Steam generation and transmission.
.182 Steam boilers.
.1821 General practice, Construction, Riveted joints, Staying, Bracing, etc.
.1822 Marine boilers.
Tubular, Scotch.
.1823 Locomotive, Traction, and Portable boilers.
.1826 Stationary boilers and settings.
Internally fired boilers : Fire-box, Vertical,
Cornish, Lancashire, Galloway, Scotch.
Externally fired boilers.
Plain cylinder, Return flue, Return tubular, French, Water-tube,
Sectional.
Boiler settings.
Fronts, Grate bars, Braces, Arch bars, Walls.
.183 Boiler fittings.
Water gauges, Cocks, Low-water alarms.
.184 Mechanical stokers, Coal and ash conveyers.
Oil feed apparatus, Burners, etc.
Damper regulators.
.185 Steam transmission and distribution.

.1851 General matter.
Flow of steam in pipes, Condensation, Velocity, Friction loss, etc.
.1852 Central station steam transmission and distribution, Street mains, Conduits, etc.
Steam fittings, Piping, Valves, Coverings, Packing, Pressure regulators, Indicating and Recording pressure gauges, Traps, Steam loop, Exhaust heads.
Steam Heating. (*See* 697., Heating and Ventilation of Buildings.)
Heating systems.
Live, exhaust.
Direct and indirect radiation.
Central coil and forced air blast.

.2 Hydraulic Engineering.

.21 Theory and general practice.
.211 Water power economy.
.2111 Systems, Instruments and Records of measurements and tests of Water power, Water wheels, Motors, etc.
.2115 Water supply. (*See* Water Works, Sanitary Engineering.)
Flow of rivers, Volume, Constancy, etc.
Reservoirs and storage.
Measurement of water flow, Weirs, Tumbling bays, etc.
Artesian wells, Well-boring machinery.
.212 Dangers, Accidents, etc.
.22 Marine hydraulic engineering.
.221 Power, Utilization of ocean waves and tide.
Hydraulic dock machinery. (*See* E .28, Hydraulic power utilization.)
Hydraulic ship propulsion. (*See* E .12, Marine steam engineering.)
.23 Mill Dams, Bulkheads, Penstocks, etc.
.232 Mill dams.
.233 Bulkheads, Gates and fittings.
.234 Penstocks.
.235 Sluices, Tail Races, Fish-ways, etc.
.24 Water wheels, Motors, etc.
.242 Overshot and Breast wheels.
.243 Undershot and Jet wheels.
.244 Turbine wheels.
.2441 Fourneyron, or Outward discharge.
.2442 Jonval, or Downward discharge.
.2443 American, or Inward discharge.
.245 Water motors, Water pressure engines, Water meters.
.25 Hydraulic pumping machinery. (*See* E .15, Steam pumps, etc. E .35, Electric pumps.)
.252 Hand pumps, Hydraulic rams, etc.
.253 Power hydraulic pressure pumps, Accumulators, etc.
.254 Power fire pumps, Hand fire engines.
.256 General power pumping machinery.
.2561 Power boiler feed and Tank pumps, Centrifugal pumps.
.2562 Power vacuum pumps.
.2563 Power wrecking pumps, Ejectors, Power deep well pumps, etc.
.26 Hydraulic power utilization.

.261 General matter.

.262 Dock machinery. (*See* E .221, Marine hydraulic engineering.)
Elevators, Hoists, Charging apparatus, Presses, Buffers, Forging and Riveting. (*See* E .95.)

.285 Hydraulic transmission and distribution.

.2851 General matter. Flow of Water in Pipes, Friction loss, Discharge orifices, Hose and Nozzles, Water hammer.

.2852 Central station hydraulic power transmission and distribution. Street mains, Conduits, etc.

.4 Hydraulic fittings, Piping, Valves, Packing, Pressure regulators, Indicating and Recording pressure gauges, etc.

.4 Heat, Air, Gas, and Oil Engineering.

.41 Theory and general practice.

.411 Gas, Oil, and Heat economy.
Systems, Instruments and Records of measurements and tests of Heat and its effects.
Gas and oil as fuel, Illuminants, etc.
Lubricating oils, Oil testing machines.
Coal *vs.* Water gas, etc.
Thermometers, Pyrometers and temperatures, Calorimeters.

.412 Dangers, Accidents, Explosions, etc.

.43 Aerial navigation.
Balloons, Flying machines, Air ships.

.44 Heat, Air, and Gas engines.

.441 Theories, General matter.

.442 Solar engines.

.443 Hot air engines.

.444 Compressed air engines, Rock drills, etc.

.445 Gas engines, Vapor engines.

.446 Windmills, Wind engines, etc.

.45 Power air pumps and machinery.

.452 Positive blowers, Pressure blowers.

.453 Power air compressors.

.456 Fan blowers, Exhausters, etc.

.48 Heat, Air, Gas, and Oil production, Distribution, etc.

.481 Production and Application of heat, Combustion.
Fuels, comparative efficiency.
Furnaces, general.
Smoke consumption, prevention.
Chimneys and Forced draught.
Chimney construction, Stability, Duty, etc.
Heating and ventilating. (*See* 697, Heating and Ventilating Buildings, and E .1852, Steam Heating.)
Drying and Evaporation.
Dry kilns and apparatus.
Evaporating apparatus.
Annealing, Hardening, and Tempering.
Annealing and Case hardening furnaces, apparatus and materials.

.482 Gas manufacture.
Plants, Retorts, Producers, Purifiers, Condensers, Storage, etc.

.483 Natural gas and oil.
Wells, Well boring and machinery.
.484 Oil producing, Refining, Purifying, etc.
Oil presses, Stills, Filters, Purifiers, etc.
.485 Heat, air, gas, and oil transmission and distribution.
.4851 General matter.
Flow of air, gas, and oil in pipes, Velocity, Friction loss, Condensation, etc.
.4852 Central station Air, Gas, and Oil transmission and distribution.
Street mains, Conduits, etc.
Compressed air power transmission.
Pneumatic despatch apparatus.
Natural gas and oil pipe lines, etc.
Air, gas, and oil piping, Fittings, Valves, Packing, Pressure regulators, Indicating and Recording pressure gauges, etc.
Dust and shavings collectors, Separators, Piping, Hoods, etc.

The following is the relative subject index covering the extended tables given above:

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Accidents.
Boiler and engine ..... .112
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Dry kilns..... .481
Dust and shavings collectors..... .4852
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heat, gas and oil..... .411
Water power, wheels, motors..... .211
Dynamometers..... .1111 ; .211
Economy.
Boiler..... .1111 : .181
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Efficiency.
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Solar..... .442
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Fuel economizers..... .1113
Fuels, gas and oil economy..... .411
comparative efficiency..... .481
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Gas condensers..... .482
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Who says: "Well, that is a useless lot of machinery! Why don't you have an alphabetical index, and go direct from that to what you want? What advantage is there in ricochetting through your classification tables?" I did not suppose, before I sent out my recent circular, above referred to, that there was a man at large in this broad land who needs to be convinced of the advantages of classing in some shape any form of knowledge or material that he expects to use; of marshalling in line all the elements of a subject and defining in some way their established relationship, so that he can study the general sub-

ject or pick out any element of it without going through it in detail. While I have discovered a few such, I am confirmed in the belief that the classification question is one of manner and extent and not of being. All considerable collections of books, papers, or materials of any sort have to be handled by some comprehensive system of classification, and the little collections can be proportionately benefited by such provision. There are numerous schemes in use, but I believe none of them approach the Dewey system in the simplicity, exactness, and clearness with which, by the decimal tables, the relationship between the component parts of a subject, and between the subject itself and kindred subjects, can be defined; in the capacity to define accurately the growth of a subject by the addition of numerals to the tables or by the decimal subdivision of numerals already there; nor in the mnemonic features which can be employed without sacrificing any essential in the classification.

The relative subject index serves to guide both the indexer and the searcher for indexed items, by the same directions, to the same classified exposition of the subject, if a study of the classification is necessary to fix the proper mark for an item, and directly to the mark itself if such study is not necessary. The classification mark once affixed tells what the item is, often more quickly and clearly than could the best definition written out, and it also tells where the item is to be put or where it is to be found, with all the other items that the collection contains of the same definition. If the classification tables be established by expert knowledge, the work of properly indexing and filing successive items can, by the aid of the subject index and under competent direction, be turned over to very ordinary intelligent labor. If the expert wishes to do his own indexing, the time he saves, in simply affixing a number to define the subject and place in the collection of the item, is worth his consideration. When it is desired to consult the information contained in the collection on a given subject, the entire resources of the collection on that subject can be withdrawn from or returned to the collection at once and intact.

So far as I have examined and understood the question, the leading competitor of the Dewey system is the alphabetical subject index with direct references to shelf, book and page, or file numbers. This plan leaves the indexer largely to his own resources with each item. If the item requires study to fix its

place, his familiarity with the subject, his shelf or file list, or the scattered alphabetical headings that may occur under the subject, must guide him. When the place is found and the shelf or file number written on the item, the index heads for each item must be written out, or hunted up in the index of the entire collection and reference to each item added in detail. The item is placed in the collection, not with reasonable certainty alongside all the items the collection contains of a given definition, but sometimes according to the accidents of orthography or the assignment of shelf numbers. When it is desired to use the material the alphabetical index of the entire collection must be handled for each item, and when found the items must be gathered one by one from their places, and then redistributed in order to be put where they can again be found.

It is proposed here to work out, not a classification for the specialist in any department, but a general scheme which can be used by all, for all their material except that which concerns the particular specialty of each, though the system is perfectly adapted to carrying out and defining the remotest details. That, of course, is a work that each individual or body of specialists may carry as far as it might be thought profitable beyond a point at which it would cease to be generally useful. For instance, I have made a detailed classification of the work of a great manufacturing industry in which I have defined in this way the component groups, motions, and parts of one of the decimal subdivisions under textile machinery; namely, looms. It may be profitable in this connection, and as a specific illustration of its general working, to notice how the decimal system meets some of the requirements of that use.

In the draughting room we used to depend on a subject index catalogue, with references to the numbers of drawers in which certain subjects were kept. Every little while some drawer would get full, and a part of its contents would be moved to new quarters. Then it became necessary to re-mark the drawer number on the removed drawings, and to hunt up and re mark the corresponding references in the drawing index book, and on the pattern number list cards. With the decimal system, each drawing is marked as soon as its character is fully determined with its classification number, which takes the place of a general title on the drawing, and fixes once for all its place in the collection. The drawings are filed in manilla portfolios which

contain a dozen or so sheets and which are marked with the classification number and filed numerically by it. When a portfolio gets too full its subject is, if necessary, further subdivided decimally, or the drawings are divided by customers' names or some other alphabetical distinction into two or more portfolios of the same class number. No subject index book is kept. The drawings, with the general relative index of the system, are their own index. No change is ever made in the reference marks on the drawing or pattern number cards, except to add a figure to the decimal mark, which happens if at all to but few drawings at one time, and which is not therefore a discouraging job. No new place for a subject ever has to be learned. When a place in the collection gets too crowded, it only costs purely manual labor to move along and provide for indefinite expansion at any point. When a new subject comes up, its classification mark is established beside related subjects or as an extended decimal of the subject of which it is a natural offshoot.

These things, while they go far toward demonstrating the practical usefulness of the system for the purpose, are but incidental to the main object in view, which is still in course of development, the provision of economical means of handling lists of motions and groups of parts in making up, pushing, and tracing detailed orders in the shop and in keeping cost of manufacture.

Now, specifically, what is the use of a general engineering classification?

It could be made a time and energy saver to all engineers who have established a habit of filing notes, catalogues, clippings, etc., in that it enables them to turn over to assistants the work of classifying, indexing, and filing ordinary material; or, if one wishes to do the work himself, in that it reduces it to a simple and manageable form. It would stimulate students and others to acquire that habit, which is in itself an educator, and which might lead to the collection and filing of valuable data which would without such incentive pass out of mind and be forgotten, or, in the absence of classification, pass into such a voluminous alphabetical tangle that it might better be forgotten. Is the man here who once started an index book, or card or envelope system of collecting notes, etc., of his reading and experience, and who finally gave it up and now keeps no such record because it was too much work for the prospective return he could see,

or because the material got so " numerous " or so badly arranged that he could find nothing in it when he wanted it? This thing would have helped him to a generous success.

The system, worked out in such form as to come into general individual use, would add the element of interchangeability to independent collections, which would thereby become of permanent and enhanced value, instead of becoming of more or less impaired value when they pass from the hands of their collectors. Worked out in a form to commend itself for the uniform indexing of engineering libraries, periodicals, and the transactions of engineering societies, the usefulness of the system would be multiplied manyfold over what would be possible confined to individual uses.

I need not, I suppose, say that it is not desired to limit discussion to the Dewey or to any decimal system. If something better can be developed, let us have that. It is to be particularly noted here that the extended tables I have given are not presented as complete or satisfactory in any sense. I am not an expert under any of the heads represented, which I have selected as better illustrating the character and capacity of the scheme than other groups I have attempted to expand. It will be noticed that many of the subheads given are not indicated decimally. This is partly due to my lack of time and knowledge to define them properly, and in some instances to a feeling that too minutely extended examples might prove confusing illustrations. I may here remark that there are in use some modifications of the strict numerical plan, which tend to relieve the possible confusion in long-extended decimals, by intermingling letters with the numerals. In one of these, the whole alphabet is added to the nine numerals, making thirty-five classes, divisions, sections, etc. It is a part of Mr. Dewey's plan to leave the letters to be used in place of figures by individuals who may desire to modify their tables from the published form, which the publishers, protected by copyright, insist shall not be used without the published meanings. This and other modifications which need not be introduced here will be fruitful studies if the work herein proposed is undertaken.

While I have contemplated the development of a classification of mechanical engineering only, the present occasion is auspicious for the discussion of a complete general classification of the whole field of engineering, which can, I think, be divided much

more satisfactorily by ignoring some of the old divisions, particularly "mechanical" and "civil," and substituting new titles based on the nature of the work. A comprehensive system developed under the joint auspices of such representative bodies as these associated in the management of the Engineering Congress, and kept up to date by a standing commission, would command a support and attain a usefulness in the economical handling of a great and growing engineering literature which cannot be measured here and now. There is another work to which such an alliance could give a great impetus. There has already been recommended by the American Society of Mechanical Engineers a standard size for trade catalogues, six by nine inches, that being also the size of the Society's Catalogue, Index, and *Transactions*. The importance to all collectors, public and private, of a standard uniform size or sizes for pamphlets and circular publications could be effectively brought to the attention of a great and influential constituency by the recommendation of the proposed commission.

DISCUSSION.

Mr. Wm. H. Jenks.—That a subject classification for notes, memoranda, etc., is desirable, may be assumed, but the extent to which this classification should be carried may depend upon the size of the collection to be classified. In classifying any collection of objects each item or group is considered as one of the members of a group composed of this and other similar members. In general, and except for special purposes, the collection need only be divided into groups of such size that any individual item may be readily found in its group. This limits the number of items which should be included in any one group, and the larger the collection the more minute must be the classification, in order that the number of items in each group may not be too large. In any complete subject classification there will be required an index of subjects, an index of items—referring each item to its subject heading—and a more or less complete system of cross references. The arrangement may be either alphabetical or by symbols (as the Dewey system), or it may be in part by symbols and in part alphabetical. At first sight the alphabetical arrangement seems simpler and more natural. For a small collection it is efficient enough, but if the classification be carried far the alphabetical arrangement becomes much more

cumbrous, and quite as artificial as the arrangement by symbols. It requires nearly or quite as frequent reference to the index, and to label an item requires the writing of many more characters, with its additional inconvenience of making more troublesome both the referring to the index and the sorting of the material, as well as the making and using of the system of cross references. To the Dewey system of symbols the greatest objection is that no group can be divided into more than ten subdivisions. This often prevents a logical arrangement, and makes the classification more arbitrary and uncertain.

As a guide in classifying I have adopted the following rules:

1. Subdivide until the groups are not too large.

2. Arrange in each group only such members as have something in common.

3. In a symbolized classification indicate each step in the division, either by using a separate class of characters, by using a division mark or division space, or by relative position of the characters.

4. For the symbols use characters which usually have a definite order of arrangement with regard to each other, and, in general, arrange the material to be classified in order by these characters.

Rule 1 is to be applied with judgment, and practically means, do not waste time in unnecessary minuteness.

Rule 2 is the ordinary rule of logic, and the better it is carried out the fewer the references needed to the index, and the better the material will index itself.

Rule 3 does away with the chief objection to the Dewey system of symbols, and renders possible a complete logical classification. If the material accumulated in any division of a subject becomes too great for convenient handling, the division may be subdivided to any needed extent by using additional characters. These additional characters may be interpolated into any group of characters in the symbol without introducing confusion or necessitating the alteration of any characters already used. Applied to shop nomenclature, rules 3 and 4 render self-indexing, to a large extent, drawings, patterns, castings, if desired, jigs and special fixtures, finished parts of machines, etc., etc. In cost accounts and shop records the resulting symbol is especially convenient in following through the shop pieces which assemble together to form a secondary part of a machine, and so on.

If the letters of the English alphabet be used alternately with the Arabic numerals, a single character in each group will admit of twenty-six subdivisions at each step indicated by a letter, and nine at each step indicated by a figure. (The figure 0 resembles too closely the letter O, and therefore should not be used.)

Using not more than two characters in each group will admit of 702 subdivisions at each step indicated by letters and 90 at each step indicated by figures.

In using the Dewey decimal classification I found the resulting classification not satisfactory, and that in classing new material the results were often uncertain. In the published tables no heading could be found that would fit, and the matter would have to be assigned more or less arbitrarily to a number already in the published tables, or else a new symbol would have to be made out and inserted in a supplementary index. At present, and until something better turns up, I am using for notes, memoranda, trade catalogues, etc., a mixed system, in which symbols are used for a few general heads, under which the material is further classed alphabetically. When enough material accumulates in any one group to justify it, a symbol is assigned to that group and entered (or at least should be entered) in the index. My index, however, is very brief, the material forming an index in itself for the most part.

I am still using to some extent the Dewey symbols, classifying most of my material under the following heads:

620.
620.2
620.3
620.4 (mostly classed by subjects, however) } as in the Dewey Decimal Classification.
620.5
620.6
621

620A Materials and behavior of.
As 620A Friction and Lubricants (with cross reference to and from 620A Friction).

620A Strength of.
620A Iron, Steel, etc.

621A Workshop practice and appliances.
621B Mechanism and Transmission of Motion.
621C Production of Power.

621C1 Fuels, Furnaces, etc.
621C2 Steam.
621C3 Steam-boilers.
621C4 Steam-engines.
etc. etc.

621D Transmission of Power.
621E Utilization of Power.

621E1 Transport of Materials.
621E2 Working and Shaping Metals.
621E3 Working and Shaping Wood.

The classification extends, of course, only so far as my own needs have carried it, but it promises well for indefinite extension.

If a committee can be induced to undertake the necessary labor, and will give us a complete classification with accompanying symbols, I, for one, shall be glad to have such a guide. It might be carried to any degree of minuteness, but it is probable that it would serve better all practical purposes if not carried too far. A few general heads are easily remembered, and, if clear, will serve to sort the material readily into groups that are not too large for alphabetical arrangement And so far as the alphabetical arrangement can be used without becoming confused, its longer title may be offset against the shorter symbol, with its necessary reference to an index.

*Wm. L. Chase.**—The objection to the Dewey system mentioned by Mr. Jenks is often urged, and with reason. One notable modification of the Dewey plan, made by Mr. Cutter of the Boston Athenæum, adds the English alphabet to the numerals, making 35 subdivisions at each step. This arrangement destroys one feature of Mr. Dewey's plan already mentioned, the use of the alphabet for individual modifications of the published tables. Most, if not all, probable demands for subdivision could be met by using the first letters of the alphabet for the authorized tables, and the final letters, the unknown symbols in mathematics, for individual modifications. In using a combination of figures and letters on the Dewey plan, the letter "O," instead of the nought, should be discarded, as the nought is especially use-

*Author's Closure under the Rules.

ful in marking material too general in its character to be subdivided in any intermediate step.

Mr. Jenks's classification rules are pretty closely exemplified in the plan of the Dewey tables. The 4th rule emphasizes the fundamental idea of the scheme, decimal subdivision. It is because no other characters have naturally so definite and so familiar an order of arrangement with regard to each other, that the numerals so nearly represent in the form of a table the natural subdivisions of a subject, best indicated, perhaps, by the genealogical chart plan.

But it is not my purpose here to urge the adoption of the Dewey system. That will stand on its merits, if known, without anybody's urging. The thing in view is to extend and develop some scheme under the general subject of engineering in so able and thorough a manner that it will come into use for the UNIFORM classification and indexing of individual collections, engineering libraries, periodicals, and the Society *Transactions*.

DXL.*

THE LIMITATION OF ENGINE SPEED.

BY CHAS. T. PORTER, MONTCLAIR, N. J.

(Honorary Member of the Society.)

THE practical limitation to high rotative speed in stationary reciprocating steam-engines is not found in the danger of heating, or of excessive wear. The causes of both these, it is now well understood, are to be looked for in defects of design or construction, commonly of both, as they generally go together, and where these do not exist in a degree which is of practical moment, a bar to the proper employment of higher rotative speed appears long before a tendency to heat or wear is to be observed. Correct designs are now generally followed, in both the fixed and the moving parts of steam-engines, and a high degree of truth is readily attained in their construction, so that it has come to be a simple matter to make engines which can be run at very high speed, quite free from either of these difficulties.

Contrary to the general belief, no objection to rapid rotation is afforded by the development of centrifugal force in the fly-wheel or band-wheel. This the following exposition will make clear.

The centrifugal force of 1 lb., making one revolution per minute, in a circle of one foot radius, is .000341 of a pound. This force varies directly as the radius in feet (R), and as the square of the revolutions per minute (r). Hence the expression $Rr^2.000341$ gives the centrifugal force in terms of the weight (W). This is a simple and convenient formula.

A handy formula is desirable for the centrifugal force developed in each one square inch of section of the rim of a fly-wheel. This is obtained as follows: In a cast-iron wheel of one foot radius, measured to the centre of gyration of the rim, the value of W, for each one square inch of rim-section, is 19.6.

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

This number, multiplied into .000341, gives .0066836 as the centrifugal force in decimals of a pound, of this ring, at one revolution per minute. As both the centrifugal force and the weight vary directly as the radius, we have the expression $(Rr)^2 \times .0066836$ for the centrifugal force developed in each one square inch of cross section of the rim of any cast-iron wheel. For example, this centrifugal force, in a wheel five feet in diameter, making 300 revolutions per minute, is 3,759.5 lbs. $(2.5 \times 300)^2 \times .0066836 = 3{,}759.5$.

This is the sum of the centrifugal stresses, exerted equally in all directions, in the plane of revolution. What is the measure of the tendency of these forces to burst the wheel?

The answer to this question, with an exposition of the nature of the action, has been given in an article which appeared in the *American Machinist* of February 23, 1884. A brief statement only will be made here.

The stress normal to any diametral plane, and which has, therefore, to be resisted by the tensile strength of two opposite sections of the rim, is the total centrifugal force divided by the ratio which the circumference of a circle bears to the diameter. In this case this stress is as follows:

$$\frac{3{,}759.5}{\pi} = 1{,}196.6 \text{ lbs.}$$

The stress must be equal in four directions, normal to two diametral planes at right angles with each other. One fourth of the stress must, therefore, be exerted in each of these directions.

The distinction must be observed between the centrifugal force itself and the effect of this force in these directions. Its resolution into its rectangular components shows the latter to be, for any angle less than 90°, greater than the former, as the sum of the sine and cosine of the angle exceeds the radius.

This gives an excess of rectangular effect, as 1.27324 : 1; or, as 4 : 3.1416.

One half of the above stress, or 598 lbs., has to be resisted by each one square inch of section of the rim. The tensile strength of good American iron, perfectly sound, may be taken at not less than 20,000 lbs. per square inch. There is no reason why the rims of band-wheels should not be entirely sound. The thickness of metal is not great, and they are cast on edge. The arms ought to be so proportioned, and their connection with the rim

such, that there will be no sudden or considerable changes of section. Then, if the wheel be cast at a proper depth in the sand, so that it will be fed under a good head and will cool slowly, freedom from internal strains, as well as soundness of metal, is assured. Assuming a tensile strength of 20,000 lbs. per square inch, we have in the case supposed a factor of safety of 33, and if the wheel be run at 600 revolutions per minute, the factor of safety will still be more than 8.

In fly-wheel rims, on account of their thickness, there is greater difficulty in securing complete soundness, and a tensile strength of 10,000 lbs. per square inch of section is as much as can be assumed with safety, especially in wheels of large section. The best care will not always be taken to make them as sound as they might be, and a wheel is no stronger than its weakest point.

The wheels of high-speed engines have generally solid rims, and no case of their bursting has, I believe, ever been known. Disasters from this cause have been confined to engines not designed to be run at high speed, and have sometimes occurred when the speed was only slightly accelerated above the normal rate. In these cases the wheels have been built in segments, with surprising disregard of necessary strength in the flanges and bolts by which the segments were held together. The American Society of Mechanical Engineers will do a good thing, if it shall adopt 10 as the factor of safety in tensile strength, to be recommended by it for all mechanical work, and shall also recommend that in segmental wheels the joints be made, if anything, a little stronger than the section of rim. In applying the formula given above, it will be safe to take, as the value of R, one-half the outside diameter of the wheel. This being greater than the diameter measured on the centre of gyration, the computed centrifugal force will be greater than that really exerted.

Again, an objection to very high speed is not found in a tendency to knock on the centres. In a properly designed and constructed engine, in which the valves are correctly set, and which is run by steam, high speed tends to silent running. Noise from bad design or bad work, from insufficient lead given to the valves, and from water in the cylinder, is excluded from consideration.

It is admitted, with pride, that the bad consequences of these defects are aggravated by high speed. This revelation of them

has wrought an entire change in engine construction, not yet completed, and even makers of slower speed engines have largely profited by it. But it is obvious that there is now no excuse for their existence. The only legitimate cause of knock on the centres is loose boxes, and knock from this cause is softened as the speed is increased, and at extremely high speed will disappear entirely, owing to the force of the steam at these points being absorbed in overcoming the inertia of the reciprocating parts.

Again, vibration is not an objection to very high speed, because it is an easy matter so to design and construct an engine, and balance the running parts, that it shall be free from vibration at any speed whatever.

Again, very high speed is not objectionable, *per se*. If an engine runs in silence, completely free from vibration, without any tendency to warm, and without wear of any running part, its very speed renders it an object of especial admiration, even to those to whom such speed is new. Whenever extremely high speed in a steam-engine has caused any other feeling in the beholder than that of admiration, it has always been the case that it has been attended with something annoying, a noise, or a jar, or some uncomfortable action, which ought not to have existed.

All this being true, there still remain two considerations of a controlling nature, which require that the rotative speed of engines shall be kept within moderate limits.

The first of these is, that engines ought not to be run as fast as they can be. It must, on reflection, be obvious to every one, that an engine should be capable of running, and that too with entire satisfaction, so far as its motion is concerned, a great deal faster than it *is* run. This is the solid ground of security and confidence. It means peace and comfort, and helps to make men sleep well o' nights. It means long life to both engine and builder. I do not know anything to which the ancient maxim, *in medio tutissimus ibis*, is more directly applicable. Observe the force of the superlative, *tutissimus*, considered as a positive statement. "in the middle course you shall go *most safely*." That is just what we want in mechanics, in all our progress, to go most safely.

The second objection to the employment of extremely high speed is a very serious one indeed. It is the large amount of waste room in the port, which is required for proper steam dis-

tribution. In the important respect of economy of steam, the high-speed engine has thus far proved a failure. Large gain was looked for from high speed, because the loss by condensation on a given surface would be divided into a greater weight of steam, but this expectation has not been realized. Far from it. The performance of this class of engines shows, instead, a positive, and in some cases a large, loss in economy. For this unsatisfactory result, we have to lay the blame largely on the excessive amount of waste room. It has been already pointed out by Mr. Harris Tabor, that the ordinary method of expressing the amount of waste room, in the percentage added by it to the total piston displacement, is a misleading one. It should be expressed as the percentage which it adds to the length of steam admission, and then every one would see what a serious thing it is. For example, if the steam is cut off at one fifth of the stroke, 8% added by the waste room to the total piston displacement means 40% added to the volume of steam admitted. Under these circumstances, it is obviously the duty, and for the interest, of builders of high-speed engines to adopt every expedient for reducing the amount of waste room, that can be done consistently with the proper admission and discharge of the steam. For this, the first requisites are moderate piston speed and longer stroke.

Engines of four, five and six feet stroke may properly be run at from 700 to 800 feet of piston travel per minute, but for ordinary sizes I would recommend and urge that 600 feet per minute be taken as the limit of piston travel, under all circumstances. This will give from 300 revolutions per minute with 12 inches stroke to 100 revolutions per minute with 36 inches stroke, with which purchasers ought to be satisfied. I would ask builders, in their own interest, to resist the temptation to get the utmost out of a given engine, and to set their faces like a flint against the demand for short-stroke engines, which shall occupy but little room, and from which the required power can be got by speeding up beyond the limit here proposed.

But I am met with the objection that, in this class of engines, large waste room is a necessity, to prevent break-down from water in the cylinder—that of the two alternatives, of waste of steam in this way, and broken cylinder-heads and pistons, purchasers prefer the former. I confess that I am thoroughly disgusted with the engineering which puts purchasers of engines

in such a dilemma as this. Getting rid of water in the cylinder seems to be the prerequisite to any attempt to reduce the amount of waste room. Then, by all means, let it be the first object of builders of high-speed engines to get rid of all possibility of water in the cylinder, in an amount capable of doing any harm.

DISCUSSION.

*Mr. Alfred Vanderstegen.**—I cannot agree entirely with the author, nor accept all the conclusions of his paper. Setting aside the bursting of the fly-wheel, which has never been a serious danger, as stated in the paper, the author presents several objections to high speed, which he divides into two classes. The first includes those due to defects in design or imperfect construction, such as heating, excessive wear, noise due to lost motion on the centres, and vibration.

The second group embraces the losses of steam due to the large percentage of clearance in the cylinders, which he considers a serious objection, and urges that for peace and comfort no apparatus should be run at the limit of its speed.

In regard to the first group of difficulties the speaker quite agrees with the author that good design and careful construction can prevent an engine from heating, wearing, or knocking on the centres, but it is his belief that the same qualities can be depended on to make an engine economical and safe.

While experience is the only ground on which a satisfactory opinion can be based, yet it must be admitted that if a high-speed steam engine can secure economy and safety in addition to all its other desirable qualities, the high speed will not be objectionable *per se* on account of the fundamental defects presented by the author. The engine in the palace of Mechanic Arts at the Columbian Exposition which moves at the highest speed is the Willans central valve engine, exhibited both in the American and the English sections.

Efficient lubrication of all the moving parts prevents their heating, and I can testify of my own knowledge, from examination of engines used for many months, that there is no excessive wear. Moreover, there is no tendency to knock on the centres, for the very efficient reason that this engine is single acting, so that the pressure on the reciprocating parts is always compressive, and

* Of Ghent, Belgium.

their inertia at the end of the up-stroke is taken up by pressure of the air in a buffer. As to consumption of steam, tests of the Willans engine show a performance nearly the same as with the best type of low-speed Corliss engines, and they run with fully the same safety as any.

In the Exposition are two engines of 350 H. P., running at about 350 revolutions, and two smaller ones of 80 H. P., running at 460. It will be observed that they make no noise at all, while the other double-acting engines are not so silent, even if well made; because the clearances in the bearings and at the joints, small as they may be, are never zero, and only can be in a single-acting engine.

In the proceedings of the Institution of Civil Engineers of Great Britain will be found the results of the tests made by the late Mr. Willans upon his engine, in which he was assisted by the most prominent engineers of his country—Professor Kennedy, Professor Unwin, and Mr. McFarlane Gray. If it be good design, careful construction, and skilful operation which are the causes of the remarkable performance of the Willans engine, preventing heating, wearing, and knocking, it ought to be the same qualities which produce the economy, because the system of distribution permits the waste room to be reduced and secures a good drainage of water, and a perfect fitting of all parts prevents leakage. If this be true, then the experience of a great number of important power stations in London proves further that nothing is to be feared from the stand-point of safety; so that my opinion is that high-speed engines can be run not only without heating, or wear, or knocking, or vibration, but they also work economically and safely when well designed, well built, and well operated.

The question of design and construction, which seems to the author quite easily to be met, remains still, I think, a principal difficulty and the only condition of success. Neither in the old country nor in the new, so far as I know, are these features of design and construction usually sufficiently accurate and careful.

Mr. A. K. Mansfield.—To hear the man whom engine students have long looked upon as the chief exponent of high rotative speeds in engines, utter such unequivocal words on the other side of the argument, is, of course, a matter of surprise. Yet the words have the right ring. I am in the service of a company which builds three types of engines, differing from each other mainly in the matter of ratio of stroke to bore, and gen-

erally known as slow-speed, medium-speed, and high-speed engines. Although we claim that the clearance spaces in all these engines * are less than in engines of other make, averaging in the three types 2%, 3%, and 5%, respectively, yet we have long ago learned to admit that the high-speed type is built to fill the demand for a cheap plant, not to improve economy in the use of steam over the other types.

We recognize a reaction toward *medium-speed* engines, and believe that papers, such as Mr. Porter's, from men of experience like his, will help this movement along and thereby improve the science of steam engineering.

Mr. Porter's statement that in case of an engine cutting off at $\frac{1}{5}$ stroke with 8% clearance space, 40% is added to the volume of steam admitted, seems to be somewhat misleading. This could only be the case in a condensing engine maintaining a perfect vacuum. In a non-condensing engine with back pressure of say 15 lbs. absolute, boiler-pressure 90 lbs., clearance 8%, and no compression, the amount of steam added is 34%, not 40%. With compression to one-half initial pressure—a usual case—it is 17%; and with 5% clearance, and compression $\frac{1}{2}$, it is $10\frac{3}{4}$%.

Mr. William S. Aldrich.—Rotative speeds are chiefly referred to by Mr. Porter, yet are often misleading for comparisons. This is more especially to be noted "in the important respect of economy of steam." It is in this respect only that Mr. Porter says: "The high-speed engine has thus far proved a failure." There is no good reason why it should continue to prove a failure.

Granting, with Mr. Porter, that the high (rotative) speed engine has its place and its use, and that it is not altogether a bad thing on that account, there are other reasons for poor economy besides waste room in the cylinder and passages. It requires positive motion valves. These are well known to be deficient in economy of steam distribution. Whenever we can obtain a clean, clear, sharp "snap" cut-off by any other means than a tripping mechanism, with its dash pot accompaniment, and having an almost instantaneous action, we may run economically at almost any speed, such as 600 revolutions per minute.

At present, the most promising method of distributing steam rapidly is by independent valves (preferably of the rotary type)

* Buckeye Engine Co.

operated by independent electromagnetic mechanisms under the immediate control of the governor mechanism, but systematically operated from the crank shaft.

That the chief difficulty heretofore has been from mechanical rather than thermodynamic causes, may be noted in the operation of the steam turbine, as Dow's, which was tested by Professor Ewing. Though I have not the exact figures at hand, I believe that the economy was from 15 to 18 lbs. per horse power per hour, directly coupled to a dynamo running at from 1,200 to 1,500 revolutions per minute. The matter was fully reported in the technical press at the time.

Respecting the limitation of engine speed in current types, Mr. Porter makes no mention of the influence of admission pressure and its relation to the piston speed in point of economy. There is a vital, and in all probability a direct relation among these quantities, other things equal. When more is definitely known of the rate of flow of steam under different pressure and varying degrees of quality, it will probably be found that the maximum economy, other things equal, will be obtained when the piston speed is made much more proportionate to the rate of flow of the steam. In other words, it is best to work the steam while it is hot, and as quickly as possible. The current empirical practice, as recommended and urged by Mr. Porter, makes the piston speed one-tenth of the assumed rate of flow of steam of 6,000 feet per minute, which Rankine gives as the approximate rate for ordinary working steam pressures.

Given the type of engine, size, and make (which involves constructive peculiarities), there is probably a most economical piston speed for any given admission pressure; and vice versa. Higher piston speeds have generally been found desirable with higher admission pressures, and with no great sacrifice of economy, notably in compound and marine types.

Valuable comparative data is furnished in the paper by Prof. W. F. M. Goss, on the "Tests of the Locomotive at the Laboratory of the Purdue University." Considering the precautions taken to avoid errors, and the maintained constancy of conditions throughout each of these tests, it seems permissible to make the following table, which involves the variable quantities under consideration while the cut-off was constant:

Cut-off.	No. of Test.	Revs.	Piston Speed.	Steam Press.	Piston Speed Steam Press.	Economy.
18.62	1	81.6	.....	100.8	.....	30.24
18.62	7	127.37	.....	109.8	....	28.97
26.92	2	79.3	.....	76.1	.....	30.13
26.92	8	128.35	.....	86.8	.....	29.18
26.92	13	78.20	.....	117.6	.....	26.77
36.27	3	80.59	.....	62.1	.....	31.29
36.27	9	128.35	... .	69.7	.....	30.33
36.27	14	76.42	... .	97.9	.....	29.48
46.70	4	79.18	.....	47.8	.....	35.40
46.70	10	128.77	.....	58.9	....	31.55
46.70	15	81.13	.....	88.5	.....	30.04
46.70	17	130.40	.....	100.1	... .	27.57
46.70	20	127.90	.....	111.8	.....	28.29

The stroke being the same in all cases, the piston speeds may be compared by simply comparing the revolutions per minute. The last set of values for the economy at 46.70 cut-off are significant. The piston speed divided by the steam pressure may offer a suitable basis for comparison, and it was thought to tabulate these for plotting a curve, but the values are scarcely numerous enough to arrive at any definite conclusions on the matter at present.

DATA FROM DENTON'S PAPER.

	Stroke.	Revs.	Piston Speed.	Pressure.	Economy.
Iona.....	39″	61.1	397.15	180	13.35
Sulzer.....	52.2″	66.4	610.88	145	12.73
Wheelock ..... H. P.	36	79	474	.....	13 11
Wheelock ..... H. P.	48	.....	632	142	13.41
Laketon.....	36	27.76	166.56	150	13.84

DXLI.*

A COAL CALORIMETER.

BY GEO. H. BARRUS, BOSTON, MASS.
(Member of the Society.)

In view of the prominence given to the determination of the quality of coal used on locomotive tests by the employment of some form of oxygen calorimeter, which is given in the report of the Committee on Locomotive Tests presented at this meeting, it seems desirable to record some of the results which have been obtained by the use of one form of the instrument referred to, as designed and operated by the writer.

The instrument has been employed for the past three years, and during that time samples of nearly one hundred different coals have been subjected to the calorimeter test. No definite line of investigation has been undertaken to determine the heat of combustion of selected varieties of coal. The tests have been made on coal which has been used on evaporative trials of boilers which the writer has conducted, and on samples which have been submitted to him from time to time by clients who wished the value of the coal obtained. A large share of the fuels are coals mined in Maryland, Virginia, and Eastern Pennsylvania. Few coals from points in the United States farther west have been tried.

It is proposed here to give a brief description of the apparatus and a tabular summary of the results of a portion of the tests.

The complete apparatus is shown in the accompanying half-tone cut (Fig. 246). The calorimeter itself, which lies at the right near the tank, consists of a glass vessel 5 inches in diameter, 9½ inches high, which holds the water of the calorimeter. Submerged in the interior is a bell-shaped glass vessel 2½ inches in diameter, 4 inches high, having a long neck ¾ inch in diameter, which is closed at the top with a stopper. The upper end of the neck stands 5 inches above the top of the outside vessel. The glass bell, or "combustion chamber," as it may be termed, rests upon a metal base, to which it is held by means of spring clips, the bottom of the chamber

* Presented at the Chicago meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

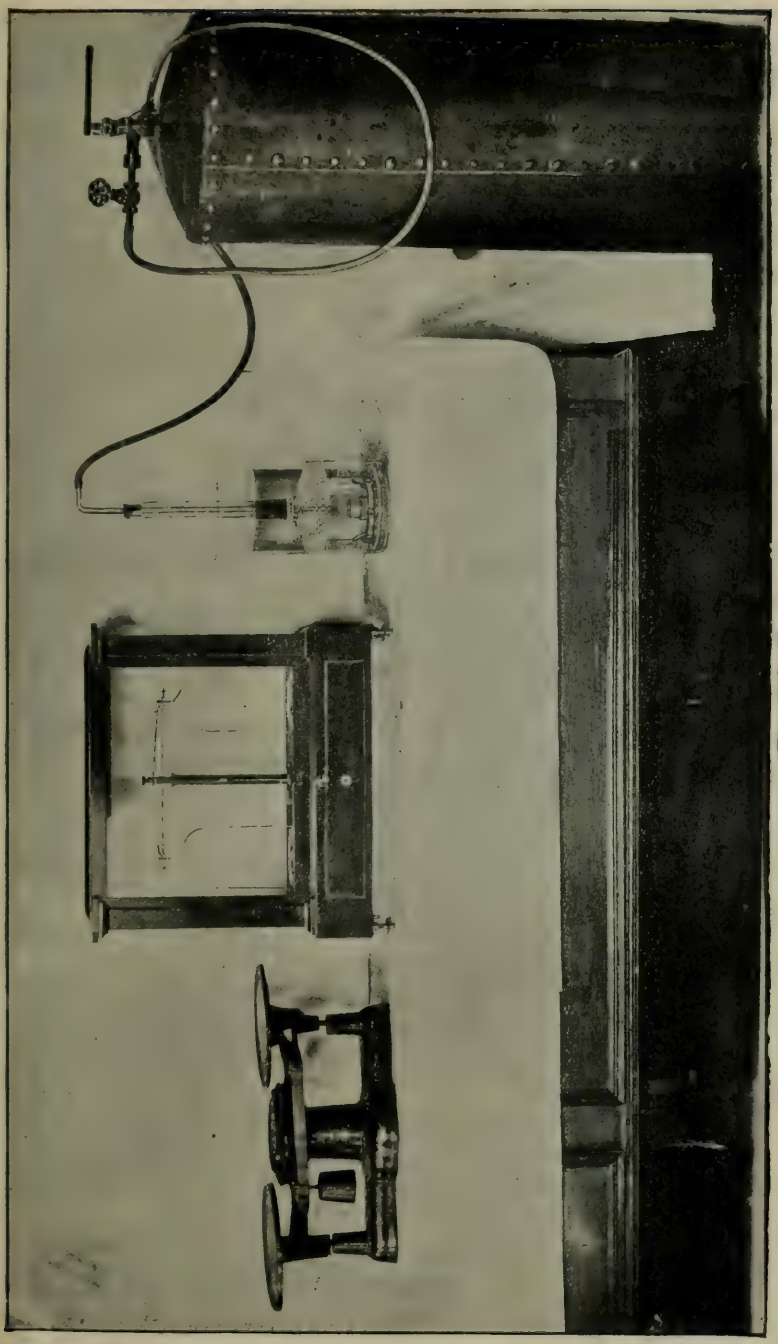

FIG. 246.

being provided with an exterior rib by means of which the clips are made fast. The base is perforated, and at the centre is mounted a short tube, for the reception of a crucible, in which the combustion takes place. The crucible is made of platinum. It is surrounded by a layer of non-conducting material, which is placed between it and the outer metal. A small glass tube is inserted in the stopper at the top of the neck, and this is carried down to the interior of the combustion chamber. It is fitted somewhat loosely, so that a slight pressure will move it up or down, and thereby adjust its lower end to any height desired above the crucible. The tube has a slight lateral movement also, so that it may be directed, at the will of the operator, toward any part of the crucible. This tube is connected with a tank containing oxygen gas, and through it a current of gas is passed, so as to enable the combustion of the coal to be carried on under water. The pressure of the gas drives out the water which would otherwise fill the chamber, and keeps its level below the base. The products of combustion rising from the crucible pass downward through the perforations in the base, escaping around the edge of the base, and finally bubbling up through the water, and emerging at its surface. A wire screen is secured to the neck of the combustion chamber, extending to the sides of the outer vessel, thereby holding back the gas and preventing its immediate escape to the surface of the water.

In making a test, the quantity of water used is 2 kilogrammes or 2,000 grammes, and the quantity of coal 1 gramme. The equivalent calorific value of the material of the instrument is 185 milligrammes. One degree rise of temperature of the water corresponds therefore to a total heat of combustion of 2,185 B. T. U. The number of degrees rise of temperature for ordinary coals varies from $5\frac{1}{2}^\circ$ to $6\frac{1}{2}^\circ$ Fahr. The thermometer used for determining the temperature of the water is graduated to twentieths of a degree; and as the divisions are about one-thirtieth of an inch apart, they may be subdivided by the eye so as to readily obtain a reading to hundredths of a degree.

The scales shown at the extreme left of the cut are used for weighing out the water, and the chemical scales shown in the centre are employed in weighing the coal and the ash. The latter are sensitive to a fraction of a milligramme.

The process of making a test is as follows: Having dried and pulverized the coal, and weighed out the desired quantities of coal and water, the combustion chamber is immersed in the water for a

short time, so as to make the temperature of the whole instrument uniform with that of the water. On its removal, the initial temperature of the water is observed, the top of the chamber lifted, the gas turned on, and the coal quickly lighted, a small paper fuse having previously been inserted in the crucible for this purpose. The top of the combustion chamber is quickly replaced, and the whole returned to its submerged position in the water. The combustion is carefully watched as the process goes on, and the current of oxygen is directed in such a way as to secure the desired rate and conditions for satisfactory combustion. When the coal is entirely consumed, the interior chamber is moved up and down in the water until the temperature of the whole has become uniform, and finally it is withdrawn and the crucible removed. The final temperature of the water is then observed, and the weight of the resulting ash.

The initial temperature of the water is so fixed by suitably mixing warm and cold water that it stands at the same number of degrees below the temperature of the surrounding atmosphere (or approximately the same) as it is raised at the end of the process above the temperature of the air. In this way the effect of radiation from the apparatus is overcome, so that no provision in the matter of insulation is required, and no allowance needs to be made for its effect.

The accompanying table presents a list of sixty-one of the tests which have been made with the instrument. In many cases the name of the mine is given, but in a large number the only information presented regarding the locality from which the coal was obtained is the commercial name by which it is known in the market. In some cases merely the general class of the coal is stated, whether bituminous or anthracite.

RESULTS OF TESTS WITH THE BARRUS COAL CALORIMETER.

Cumberland Coals.

Number for Reference.	Kind of Coal: Mine or Locality.	Percentage of Ash.	Total heat of combustion per pound of	
			Coal.	Combustible.*
1	.....	7.6	13,868	15,008
2	.....	8.2	14,058	15,313
3	George's Creek.....	6.1	14,217	15,140
4	" "	6.6	13,925	14,908
5	" "	8.6	12,874	14,085
6	" "	6.5	12,921	13,819
7	" "	7.	13,360	14,365
8	" " (American Co).....	5.	13,487	14,196
9	" " (Md. Coal Co.).....	5.1	13,656	14,389
10	" " (G. C. Coal and Iron Co.)..	5.7	13,424	14,235
11	.....	6.1	13,534	14,413
12	George's Creek.....	5.1	13,745	14,483
13	.....	7.5	13,617	14,721
14	Eureka.....	5.1	13,653	14,386
15	"	5.4	13,427	14,193
16	.....	8.	12,973	14,101
17	George's Creek.....	4.4	13,923	14,563

Miscellaneous Bituminous Coals.

18	Pocahontas.....	6.2	13,608	14,507
19	"	4.	14,121	14,709
20	"	5.	14,114	14,856
21	"	6.5	13,697	14,649
22	"	3.2	14,603	15,685
23	Clearfield.....	4.7	13,640	14,312
24	"	11.1	12,517	14,079
25	New River.....	0.6	14,273	14,359
26	"	1.	14,455	14,601
27	"	5.7	13,858	14,695
28	"	3.5	13,922	14,426
29	"	5.	13,858	14,587
30	"	4.1	13,922	14,517
31	Welsh (English)	7.7	13,581	14,713
32	Lancashire (English).....	6.8	12,122	13,006
33	.....	8.7	13,402	14,679
34	.....	11.	12,983	14,587
35	Sonman	6.9	13,326	14,313
36	"	8.3	13,267	14,467
37	"	7.	13,210	14,204
38	Elenora.....	7.5	12,765	13,800
39	"	6.8	12,877	13,816
40	.....	7.6	13,016	14,086
41	.....	9.1	12,956	14,253
42	Eclipse.....	2.7	14,114	14,505
43	.....	5.2	13,474	14,213

* Added since the meeting.

Number for Reference	Kind of Coal: Mine or Locality.	Percentage of Ash.	Total heat of combustion per pound of	
			Coal.	Combustible.*
44	.....	16.5	11,677	13,984
45	Elk Garden.....	7.8	13,180	14,295
46	Mixture New River and Cumberland...	6.7	13,361	14,320
47	Frontenac (Kansas).....	17.7	10,506	12,765
48	Cape Breton (Caledonia)	8.7	12,420	13,456
49	Youghiogheny—lump (Acme).....	5.9	12,941	13,752
50	" —slack (Pacific).....	10.2	11,664	12,988
	ANTHRACITE COALS.			
51	Honey Brook—Chestnut No. 2.....	12.	11,733	13,332
52	Cross Creek— " "	10.5	11,521	12,872
53	Lackawana—Egg.....	17.5	11,104	13,459
54	Broken	9.1	13,189	14,509
55	.....	10.6	12,812	14,331
56	.....	14.5	11,470	13,415
57	.....	11.7	12,146	13,755
58	.....	10.9	11,634	13,057
59	.....	9.3	12,201	13,452
60	.....	15.	11,086	13,042
61	.....	13.2	12,412	14,299

DISCUSSION.

Mr. Wm. Kent.—This matter of coal calorimetry is one of which I have made a considerable study during the last ten years, and I think it is a matter of much importance to the engineering profession. The coals of the west, especially, are being wasted in enormous amounts, for one reason because we do not know the difference between a good coal and a bad coal. Now, if we had a convenient coal calorimeter we could value the coal, and thus make an immense saving in money by buying better coal, or by paying for coal in proportion to its heating value.

In regard to these tables which Mr. Barrus has presented, I notice a great variation in the heating value of different coals of the same name; for instance, the George's Creek coal. We in the east understand that that is one of the best steaming coals and one of great uniformity, but Mr. Barrus' tests show a difference of about ten per cent. in two samples. Is it possible that that coal varies ten per cent. in quality after subtracting the ashes? That is, that the carbon and the volatile

* Added since the meeting.

matter after being deprived of moisture have a variation of ten per cent. in quality? I scarcely think it is possible. I think such a statement as that should be carefully tested to see if it is a fact.

In this connection I wish to call the attention of members to a paper on *Coal Calorimetry* recently published in France, by Mons. P. Mahler,* which is the most elaborate scientific research into the analyses of coals that I know of. Mahler's calorimeter is, I think, a better one than the one described here. When tested under all conditions it was found to be most accurate. It consisted of a steel vessel in which a certain amount of coal was placed, and then oxygen was forced in under a pressure of 375 lbs. to the square inch, and then the coal was ignited by an electric spark and the explosion took place. I had occasion to review Mahler's work lately, and wrote an account of it for the book entitled *The Mineral Industries*, published by the *Engineering and Mining Journal*. I hope that in future tests, in connection with the boiler tests, there will be given the results of the coal calorimeter tests and the chemical analysis. In my study of M. Mahler's tests I have shown that the proximate chemical analysis and the ultimate chemical analysis both give very close indications of the heating value really found by the coal calorimeter. That is, if you have the ultimate analysis of a coal, then by the use of Dulong's law † you can predict what that coal will give in the calorimeter within three per cent. If you have only the proximate analysis you can predict even from that very closely what the heating value of the coal is. I will not say accurately.‡ This is a matter of great importance in studying coal. When we have a coal tested in the coal calorimeter, we find that it should give a certain value. We test it in the steam-boiler, and we find that it does not give anything like that value.

* "Contribution à l'Etude des Combustibles: Determination Industrielle de leur Puissance Calorifique." Par M. Mahler. Bulletin de la Société d'Encouragement pour l'Industrie Nationale.

† Dulong's formula as modified by Mahler is

$$Q = \frac{1}{100}\left[8140 + 34500\,H - \frac{(O + N - 1)}{8}\right]$$

in which Q is quantity of heat in centigrade units, and H, O, and N the percentages of hydrogen, oxygen, and nitrogen.

‡ *Added since the meeting.*—My conclusions from a study of the tests of Johnson, Scheurer-Kestner, Mahler, etc., after plotting the results on a diagram in

We find in the anthracite region that we can get 75 per cent. of efficiency, but if we go west of that region we can hardly get 60 per cent. of the amount of heat which is reached in a coal calorimeter. That opens the whole subject—what are we to do in the western country to overcome that difference between 55 to 60 per cent. efficiency obtained in the west, and the 65 to 70 per cent. efficiency which we get in the east, with anthracite coal.

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which abscissas represented the fixed carbon in the coal, dry and free from ash, and the ordinates the heating value, as published in *Mineral Industry*, are as follows:

1. Mahler's results group themselves very closely about the average curve of the diagram, indicating that there is a law of relation between the composition of the coal as determined by proximate analysis and the heating value. Knowing, therefore, the percentage of fixed carbon in the dry coal free from ash, we may, in the case of all coals containing over 58% of fixed carbon, predict their heating value within a limit of error of about 3%.

2. This close grouping of several tests about an average curve indicates great uniformity of action of the calorimetric apparatus, and a high probability of its accuracy, unless there is a constant or a uniformly proportional error, which is not probable to any important extent.

3. Mahler's results are regularly lower than those of Scheurer-Kestner for coals of similar composition, and more closely approximate the theoretical heating power as determined by Dulong's formula; indicating that Scheurer-Kestner's apparatus and results were not as accurate as those of Mahler, and that Scheurer-Kestner's observation that the heating power of coals is generally greater than that determined from their composition is not true to the extent believed by him, especially in the case of coals containing over 70% of fixed carbon.

4. From the average curve through Mahler's results the following table may be constructed:

APPROXIMATE HEATING VALUE OF COALS.

Percentage of fixed carbon in coal dry and free from ash.	Heating Value.		Percentage of fixed carbon in coal dry and free from ash.	Heating Value.	
	Calories.	British thermal units.		Calories.	British thermal units.
97	8200	14,760	63	8400	15,120
94	8400	15,120	60	8100	14,580
90	8600	15,480	57	7800	14,040
87	8700	15,660	54	7400	13,320
80	8800	15,840	51	7000	12,600
72	8700	15,660	50	6800	12,240
68	8600	15,480			

Below 50% of fixed carbon the law apparently does not hold, as is shown by the tests of some of the lignites which depart considerably from the average curve. Cannel coal and turf from Bohemia, tested by Mahler, lie far above the average curve.

Mr. A. A. Cary.—I think that this paper deserves more than passing notice, as it treats of a subject which promises to be of the greatest interest and importance to those who are in any way interested in the economical generation of steam; and this method which Mr. Barrus has perfected and which he has so ably described, surely will, in the future, serve to teach manufacturers and other steam users how to determine the true value of the fuel they are buying in advance, and afterwards to determine whether they are receiving what they are paying for, and thus they may be relieved from taking the irresponsible assertions of coal drummers whose coal is generally valued by the persuasiveness of their remarks. We buy almost every article, outside of coal, and pay for them according to their quality; but coal for steam purposes is seldom bought in this way, and the reason has been, that the majority of steam users have not had a simple, inexpensive and accurate method for determining which coal will bring them the greatest return for the money invested.

Mr. Barrus has now brought before us the best and most satisfactory instrument of this kind I know of, and I think it is a much-needed instrument which will assist, not a little, to eventually force the coal producers and the coal dealers to offer their coal to the steam producer and others, according to its true value in producing the various economical results.

The mechanical engineer cannot fail to appreciate the value of this simple instrument. We have in boiler tests been able to make direct comparisons of the evaporation in different boilers working under widely varying conditions by reducing the evaporation to its equivalent "from and at 212°." Why should we not determine the true calorific value of the fuel we are using in a test with an instrument such as has been described by Mr. Barrus, and, in a similar manner, make our comparisons in different boiler tests more complete by doing away with the consideration of the kind of fuel used and by reducing it to a standard, say that of pure carbon?

I surely believe that this will be a requirement in most of the carefully conducted boiler tests before many years.

The Chairman.—It would seem that this ought to be an interesting subject. A few years ago I visited the West Chicago pumping station, and I found that they were paying for their coal by the water it evaporated, and not by the ton.

Mr. Barrus.—As to the variation between different samples

of coal shown in the paper, I think there is that variation because I have made repeated tests of the same sample, and corroborated the results obtained before. I have enough confidence in the results of these tests to believe that the figures given are substantially correct, and if the tests were all repeated I should get substantially the same results again. I do not make any claims for this instrument. I do not consider that it is the best ever made, but as you see from the cut of it, it is very simple, and I know it is very easily operated, and I give it to you for what it is worth. In regard to the bomb calorimeter, I know little about it, but it seems to me that it stands to reason that with tests made with an instrument like the one described in the paper, where you can watch the combustion, the result is more to be relied upon than that obtained from an instrument where the whole thing goes off in a second, and you know nothing about what action takes place inside of the bomb.

DXLII.*

TESTS OF THE LOCOMOTIVE AT THE LABORATORY OF PURDUE UNIVERSITY.

BY W. F. M. GOSS, LAFAYETTE, IND.

(Member of the Society.)

A YEAR ago, there was presented to this Society a description of the plan of mounting a locomotive then but recently added to the equipment of the Engineering Laboratory of Purdue University. The present paper gives the results of twenty tests of this engine, made during the last school year.

While the description † already referred to makes unnecessary at this time a detailed account of the accessory mechanism, it may be well to state that the locomotive is mounted with its drivers upon supporting wheels which are carried by shafts turning in fixed bearings, thus allowing the engine to be run without changing its position as a whole. Load is supplied by four friction brakes fitted to the supporting shafts, and offering resistance to the turning of the supporting wheels. Traction is measured by a dynamometer attached to the draw-bar. The boiler is fired in the usual way, and an exhaust blower above the engine, but not in pipe connection with it, carries off all that may be given out at the stack.

The tests have been conducted as a part of the regular work of students in the laboratory. Every precaution has been taken to avoid errors. The students participating are well-trained observers, and all numerical results have been carefully checked by independent workers. The work has been under the immediate supervision of Mr. Richard A. Smart, assistant in the laboratory, and the coöperation of Messrs. Off and Thomson, students in the laboratory, has materially assisted in making possible the presentation of data at this time.

It is noteworthy that, notwithstanding the newness of the plant,

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

† "An Experimental Locomotive," No. 490, p. 427, Vol. XIII., *Transactions* A. S. M. E.

every test reported has been run without stop, or any change of condition which might be charged to the imperfect working, either of the engine itself or of the mounting machinery. In Test No. 2 the throttle was closed for an instant in response to the signal gong, the cord of which was pulled by accident, but in no other was there an interruption of any sort. The sum of the distances run by the several tests is about eleven hundred miles. The engine counter at the end of the tests showed 783,824 revolutions, indicating that the engine had, up to that time, run a total of 2,440 miles.

It is but proper to add in this connection that, while the plant as it now stands offers exceptional opportunities for experimental work, it should not be viewed as a perfectly complete arrangement, neither should the data presented be looked upon as setting forth the writer's view of the scope of the work to which the plant may be applied. Thus far, an effort has been made to secure accurate data of simple engine and boiler tests under some of the more common conditions of locomotive operation, all conditions during each individual test remaining constant. The results are not wholly free from discrepancies, but it is hoped that, by the addition of accessory apparatus to increase the possible accuracy of observations, such discrepancies will be avoided in future work. Provision will also be made for the study of effects which, in the general investigation of the performance of a locomotive, are in the nature of details.

The behavior of the Alden friction brakes which serve to load the engine cannot fail to be interesting. While it is true that none of the tests reported show the engine under its maximum load, enough has been done to prove the brakes fully able to absorb all the work that the locomotive can do, whether it be run at high or low speed. The first twelve tests were run with but two brakes in place, the remaining ones with four brakes.

The balancing of the locomotive is doubtless more than ordinarily good. Early trials showed that, below 80 revolutions per minute, the lever dynamometer satisfactorily transmitted the stress in the draw-bar without the intervention of a dash-pot, but that any considerable increase above this limit resulted in an unsteady motion, there being at certain speeds a time vibration which was not easily controlled. A 10-inch dash-pot was first attached to the main lever of the dynamometer, at such a point as would make it possible for the dash-pot to receive a

stress equivalent to about one-sixth of that in the draw-bar. This addition required a correction of 209 pounds to be added to the value of the weights upon the scale-pan, to give the correct draw-bar stress. This dash-pot was in use during all of the tests herein reported. For the later tests, a similar dash-pot was placed in a horizontal position between the framework behind the locomotive, and a bracket attached to the under side of the foot-plate. This dash-pot has no connection with the dynamometer. These devices have made it possible to run at speeds as high as 300 revolutions with a very small longitudinal movement of the engine. The matter of more perfectly balancing the engine is now receiving attention.

THE LOCOMOTIVE.

The principal dimensions of the locomotive are as follows:

Total weight (*makers' figures*)		85,000 lbs.
Weight on four drivers (*makers' figures*)		56,000 lbs.
Total wheel base		22 feet 11 inches.
Driving-wheel base		8 feet 6 inches.
Cylinders:		
Diameter		17 inches.
Stroke		24 inches.
Ports:		
Length		16 inches.
Width of steam ports		$1\frac{1}{4}$ inches.
" " exhaust port		$2\frac{1}{2}$ inches.
Richardson balanced valves:		
Maximum travel		6.53 inches.
Outside lap		$\frac{3}{4}$ inch.
Inside lap		$\frac{1}{32}$ inch.
Piston displacement, cubic feet:		
Right side	Head end	3.1525
	Crank end	3.0540
Left side	Head end	3.1525
	Crank end	3.0540
Clearance, per cent. of piston displacement:		
Right side	Head end	9.390
	Crank end	10.265
Left side	Head end	9.980
	Crank end	10.019
Indicated horse-power constants:		
Right side	Head end	.01375
	Crank end	.01332
Left side	Head end	.01375
	Crank end	.01332

Drivers :	
Nominal diameter	63.
Actual circumference at beginning of tests	197.25
" diameter " " " "	62.786
Boiler :	
Diameter, waist at front end	52.
" tubes	2.
Number of tubes	200
Width of fire-box	34.5
Length "	72
Total heating surface, square feet	1214.4
Grate surface	17.5
Pounds of water in boiler when filled to middle gauge	8450
Steam space in boiler when filled to middle gauge, cubic feet	52.8
Ratio of steam space to entire cubical capacity of boiler	.29
Exhaust nozzles (double), diameter	3.

A section of the valve and its seat, is shown by Fig. 315.

The quadrant of the reversing lever has 31 equally spaced notches, 15 on each side of the centre. The diagram (Fig. 316) shows the valve action for forward motion. The curves repre-

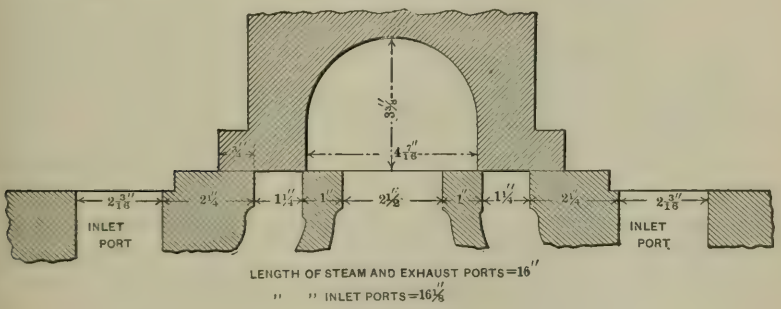


FIG. 315.

senting the valve travel, and port opening, are plotted from points obtained from the motion of the left valve-spindle while the engine was under steam. The curves representing the events of the stroke show the average of the events for the four cylinder ends. To secure the figures upon which the latter curves are based, and which are given in part in columns 13, 18, and 23 of the data, indicator cards were taken from the four cylinder ends while the engine was run under conditions which would best develop the several events of the stroke upon the cards. This was done for every position of the reversing lever, and ordinates

were located upon selected cards. The results were checked by plotting. Factors thus obtained were used as constants in working the cards of the test.

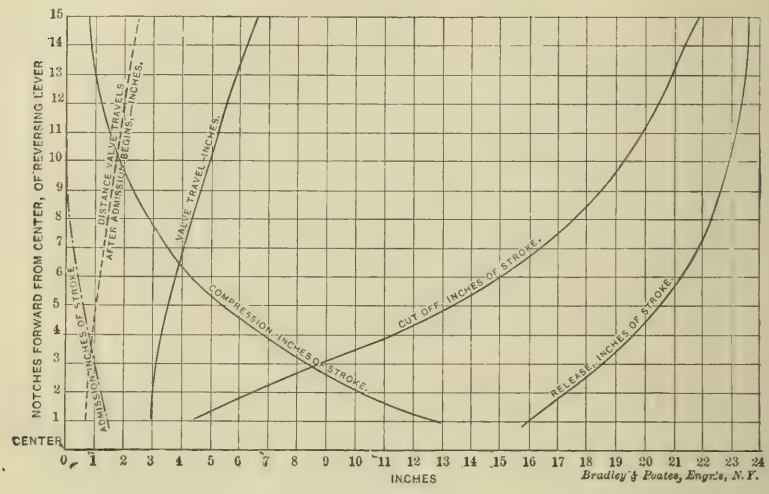

NOTCHES FORWARD FROM CENTER, OF REVERSING LEVER
CENTER
INCHES
ADMISSION, INCHES OF STROKE
DISTANCE VALVE TRAVELS AFTER ADMISSION BEGINS, INCHES.
VALVE TRAVEL, INCHES.
COMPRESSION, INCHES OF STROKE.
CUT OFF, INCHES OF STROKE.
RELEASE, INCHES OF STROKE.
Bradley & Potter, Engr's, N.Y.

FIG. 316.

METHOD OF CONDUCTING THE TESTS.

Observers were stationed for each test as follows:

Station	Number of Observers.
To keep running log, time and gong	1
To weigh fuel; also to note time of starting and stopping injector, and to keep log of same	2
To weigh feed-water, to observe temperature, and to keep log of same.	2
To operate indicators; also to take calorimeter readings, dry-pipe pressure, draft-gauge and pyrometer readings	4
To read engine and supporting-wheel counters; also to take boiler pressure, and the water pressure upon the several brakes	2
To occupy the engineer's box	1
Total number of observers	12

Besides these, there were a supervisor of tests, a fireman, and three regular attendants of the laboratory who gave attention to the mounting and accessory machinery.

Blanks for data were used in each test as follows:

A *Fuel Log*, upon which are arranged several series of four columns each, in which columns are entered (1) the weight of

each filled box of coal, (2) the weight of the emptied box, (3) the difference, or the weight of coal, and (4) a time check by means of which may be seen the weight delivered in each 10-minute interval; a *Feed-water Log*, similar in form to that of the fuel log, and showing the weight and number of barrels of water delivered in equal intervals of time, also showing the temperature of the water at the time of each gong, the latter entry serving as a time check; a *Calorimeter Log*, arranged for the data necessary to the determination of the quality of steam; a *Running Log*, providing for the number and time of gong, revolutions of drivers, difference of revolutions, steam pressures, dynamometer reading, water pressure upon brakes, draft, temperature of smoke-box, and any other observed data not otherwise provided for; a prepared blank upon which are recorded *Pressures from Indicator Cards* in columns of four groups, one for each end of each cylinder; and a *Summary Sheet*, containing the general constants for the locomotive, and the constants for the test, and receiving, as the test is worked up, the final summarized results from all of the sub-logs, and, finally, all calculated results which may be derived from observed data; hence this sheet constitutes a complete summary of the test.

In preparation for a test the engine was usually run under a light load and at a low speed for an hour or more in the morning. After the noon stop, it was started again with a light fire, the reverse lever being at once brought to the position it was to occupy during the test. The load and speed were gradually increased until the conditions for the anticipated test were reached. The ash-pan was then cleared, and upon the stroke of the gong, from ten to thirty minutes after starting, all observations were taken and the test was considered as commenced. The observations were repeated at 10-minute intervals. Throughout the test it was the purpose to maintain all conditions as nearly as possible constant. If, at the end of the first or second 10-minute interval, the speed was found to be a little too far from that desired, the throttle was moved slightly. Aside from this adjustment early in the test, and changes due to small variations of steam pressure, there was no perceptible change of condition.

The tests were ended as they were begun: that is, upon the stroke of the gong, care being taken to have the water at the starting levels, and to see that the fireman took no advantage of the

anticipated stop. The weight of coal upon the grate at the end of the test was assumed to be the same with that upon the grate when the test was begun. Within a few seconds after the last gong, the engine was stopped and the fire immediately dumped and quenched.

The speed was determined by means of a registering counter attached to the rear driver. Recently there has been added a Boyer railway speed recorder.

The feed-water was received from a service pipe into a weighing barrel of about 350 pounds capacity, and thence delivered to a small tank from which the injectors drew their supply. There were no losses of steam from the boiler excepting by the calorimeter, and, though this amount was very small, the weight of steam supplied to the engine has been corrected for it. Loss from the injector overflow for a few of the early tests, was estimated from weights obtained upon repeated trials. In the later tests, all water passing the overflow was drained to a barrel and gauged. Water thus accounted for, was deducted from the amount weighed to the boiler. No credit was given the boiler for heat imparted to it.

A throttling calorimeter was attached to the steam-pipe within the smoke-box, and gave the quality of steam in the dry-pipe. The quality of steam in the boiler was calculated from its known condition in the dry-pipe, upon the assumption of adiabatic expansion from the pressure of the boiler to the pressure of the dry-pipe.

The coal used was Brazil (Ind.) block,* which burns freely and without clinker. An analysis gave the following results:

Moisture	13.05 %
Combustible volatile matter	32.34 %
Fixed carbon	48.78 %
Ash	5.81 %
Total	99.98 %

The coal was broken into small lumps and shoveled into a weighing-box of 275 or 300 pounds capacity. From the box it was dumped as needed within easy reach of the fireman. It was

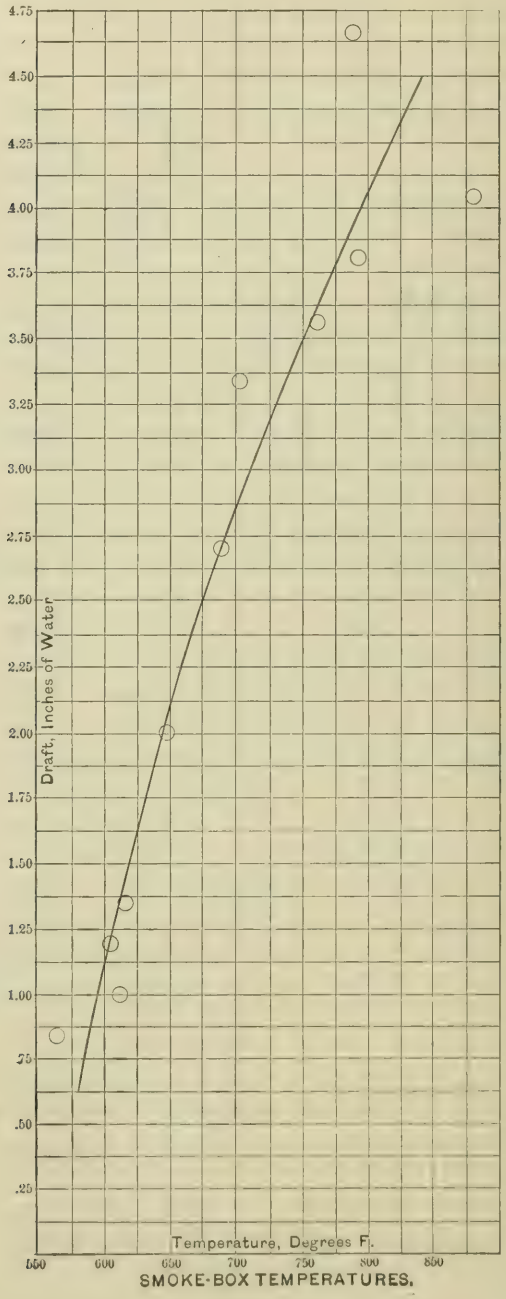
* An exception in the use of this coal is to be made in case of Test No. 14. This test was made at a time when block coal could not be obtained, and it was, therefore, run with Brazil lump coal. The deductions based upon fuel consumption are omitted for this test.

found impossible to obtain equally dry coal for all tests; hence, in the course of a test, a fair sample of about 50 pounds was carefully weighed in a galvanized iron bucket, and dried until it would give off dust when shaken; it was then reweighed and its loss determined. The weight of all the coal used for a test was corrected in the same proportion. The correction was always small, averaging not much more than one per cent.

Four indicators were used at the cylinders, thus giving seventy-two cards for a three-hour test. The steam connections were close, the drum motion absolute, and the cord short. The results given are based upon the average of all cards taken.

Draft was measured by a U-tube attached to the wall of the laboratory and connected with the smoke-box by a small pipe. The difference of level of the two water columns in the U-tube was read from a scale to tenths of inches, and the several readings for each test averaged.

Data concerning smoke-box temperature were sought, in the early tests, by use of a metallic pyrometer. A new instrument from a reliable maker, having a stem 48 inches long, was set horizontally across the center of the smoke-box, about 5 inches in front of the tube-sheet. Its indication for the first test was probably not far from correct, but when the boiler had cooled off, its indications for the lower temperature were more than 150 degrees too high. Repeated trials showed that it was impossible to get a correction for it which would hold good through two successive tests, and its further use was abandoned. Resort was then had to a copper-ball calorimeter which had been used in previous tests, the particular arrangement of which may be described as follows: A piece of one-inch steam-pipe threaded at one end, is screwed through the shell from the inside of the smoke-box. It is set radially about four inches from the front tube-sheet, and inclines from the centre of the smoke-box downward. The threaded end passes through the shell a sufficient distance to receive a cap. The cap serves to close the end of the pipe, and also to carry a light rod, to the opposite end of which is attached a simple piston fitting loosely to the bore of the pipe. A copper ball $\frac{3}{4}$ inch in diameter, and a copper vessel suitably enclosed to prevent radiation, complete the outfit. In using the apparatus, the copper ball is inserted in the bore of the pipe, the piston applied below it, and both are pushed up the pipe until the cap at the lower extremity of the piston-rod meets the lower end of the


4.75
4.50
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1.75
1.50
1.25
1.00
.75
.50
.25
Draft, Inches of Water
550
600
650
700
750
800
850
Temperature, Degrees F.
SMOKE-BOX TEMPERATURES.

FIG. 317.

pipe. The cap is then screwed in place, closing the pipe and retaining the ball at the center of the smoke-box. Here it is allowed to remain from 40 to 60 minutes, after which interval it is assumed to have come to the temperature of the smoke-box. The cap is then unscrewed and the piston quickly withdrawn, allowing the ball to roll down the pipe into the water contained in the copper vessel. From the known weight of the ball, the

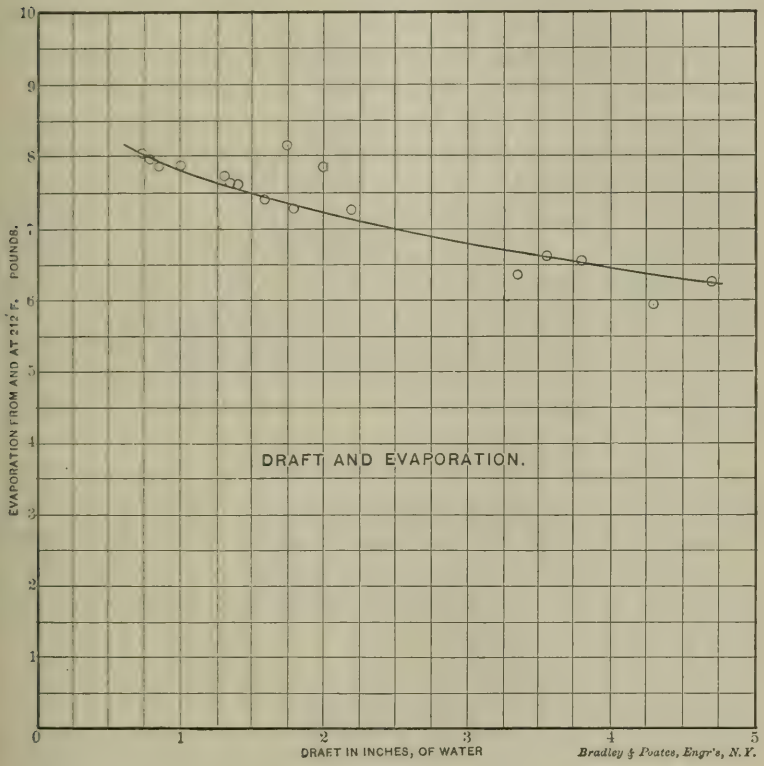


FIG. 318.

water, and the copper vessel, and from observed changes of temperature, the original temperature of the ball is calculated. The average result of three such determinations was assumed to be the temperature of the smoke-box for the test. Using the data thus obtained for eleven tests, not all of which are among those reported, a curve has been plotted with the draft as ordinates and the smoke-box temperature as abscissæ (Fig. 317), and from this curve the temperature has been determined for the tests

for which no direct experiments were made. These assumed temperatures are marked with a star in the tabulated data.

The actual and the equivalent evaporation per pound of coal are given in their proper place. These factors vary considerably, and it has seemed desirable to take advantage of the large number of tests in obtaining mean results. It may be assumed that, other things being equal, the evaporation depends upon the draft. Thus, in the diagram shown by Fig. 318 may be seen points representing the evaporation from and at 212°, for each test, plotted in terms of the draft. A smooth curve drawn through these points will serve to show the assumed evaporation for any test when its draft is known. This assumed evaporation has been found for each of the tests reported, and the result is presented in column 116.

The B. T. U. taken up by the boiler per pound of coal, the pounds of coal per indicator per horse-power per hour, and the dynamometer work in foot tons per pound of coal, as based upon observed data, are given respectively in columns 87, 68, and 114. These factors have also been recalculated on the basis of the assumed evaporation with the results given in columns 117, 118, and 119.

CONSTANCY OF CONDITIONS.

The draw-bar stress was practically constant during each test, the mechanism of the dynamometer automatically regulating the load upon the brakes. The construction is such that any movement of the dynamometer lever from its central position is met in the brakes by a change of water pressure which operates to restore the lever.

The speed for all tests was controlled by the throttle which, as previously stated, was rarely moved during the progress of a test. If the steam pressure changed, there was a corresponding change in the speed, but the fluctuations of pressure were slight. Taking Test No. 18 as a representative one, the average number of revolutions per ten minutes was 1,315; the greatest number for any 10-minute interval was 1,383; and the lowest number 1,205, giving a maximum variation, from the mean speed, of 8 per cent. only.

The mean effective pressure varied with the accelerations of speed, and somewhat because of the reduced friction of the engine itself as the test proceeded. The average for all cards from

the head end, left side, during the test already quoted (18) is 60.26, the lowest is 58.26, and the highest is 61.6, giving a maximum variation from the mean of not quite 5 per cent. During all but the very light-power tests, the injector was constantly in action and the amount of water and coal weighed out during each 10-minute interval was nearly the same. No steam was lost from the safety valve during any test.

As a means of operating a locomotive under constant conditions, it will appear, from these considerations, that the plan of mounting in question has been successful.

LENGTH OF TESTS.

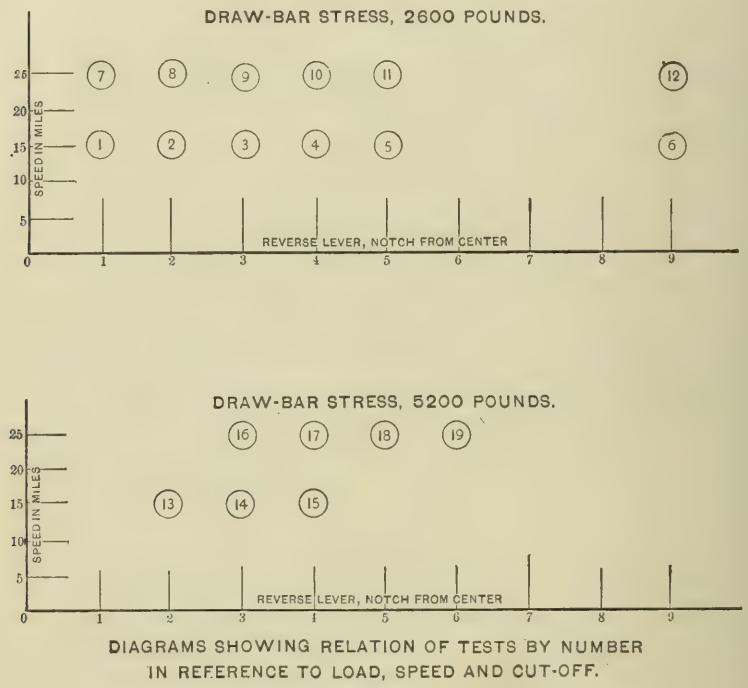
Tests at light load and low speed were of three hours duration; those of heavier load and higher speed were somewhat shorter. The shortest consumed two hours.

It is obvious that, where the conditions are maintained as nearly constant as those which have been described, the principal gain in prolonging the test is in diminishing the effect of errors in stopping and starting. The extent of these errors depends upon the accuracy with which observations are taken, and the relation of probable inaccuracies to the totals of the test. For a locomotive, the totals of steam and water consumed are enormous when compared with similar factors for a stationary boiler-plant of like dimensions. In determining the steam consumption, the error incident to starting and stopping probably does not in any of the tests reported exceed 1 per cent., so that little would have been gained by making the tests longer. The record of fuel consumption is subject to greater error than that of steam consumption, but the repetition of tests giving draft conditions nearly similar, permits a comparison of results which must lead to the detection of error in individual tests, as has been already shown.

The relation of tests from 1 to 19 inclusive, with reference to load, speed, and cut-off, is shown by Fig. 319. Test No. 20 was run with a draw-bar stress of 6,200 lbs., and at the same speed and cut-off with No. 17. This test was witnessed by Messrs. William Forsyth, James E. Denton, D. L. Barnes, and A. S. Vogt, from the Society's Committee on "Standard Methods of Locomotive Testing," and also by Mr. C. H. Quereau, Member of the Society.

In the presentation of indicator cards (Figs. 320, 321, and 322)

the series for tests from 7 to 12 inclusive is represented by cards from each end of each cylinder; all other tests are represented by cards from the right side only. The cards shown have in each case been selected to represent as nearly as possible the average condition of the test, but the mean effective



DIAGRAMS SHOWING RELATION OF TESTS BY NUMBER IN REFERENCE TO LOAD, SPEED AND CUT-OFF.

FIG. 319.

pressure which is entered upon each card, is that which belongs to the card; it is not the average for the test. Upon the ordinate at the initial end of each card, are marks representing, respectively, the boiler and the dry-pipe pressure.

Data for the tests are as follows:

Number of test.	Duration of test, minutes.	Corrected reading of traction dynamometer, pounds.	Speed.				Reverse lever, notch from center, forward.
			Total revolutions.	Revolutions per minute.	Miles equivalent to total revolutions.	Miles equivalent to revolution per hour.	
1	2	3	4	5	6	7	8
1	180	2,609	14,695	81.60	45.6	15.2	1
2	180	2,609	14,275	79.30	44.4	14.8	2
3	180	2,609	14,056	80.59	45.2	15.1	3
4	180	2,609	14,254	79.18	44.4	14.8	4
5	180	2,609	14,364	79.80	44.7	14.9	5
6	180	2,609	14,405	80.02	44·8	14.9	9
7	180	2,609	22,925	127.37	71.4	23.8	1
8	180	2,609	23,106	128.35	71.9	24.0	2
9	180	2,609	23,125	128.47	72.0	24.0	3
10	180	2,609	23,179	128.77	72.2	24.1	4
11	180	2,609	23,066	128.14	71.8	23.9	5
12	180	2,609	23,067	128 15	71.8	23.9	9
13	180	5,156	14,077	78.20	43.8	14.6	2
14	180	5,209	14,520	76.42	45.2	15.1	3
15	180	5,209	14,605	81.13	45.5	15.2	4
16	140	5,209	19,946	136.04	59.2	25.4	3
17	140	5,209	18,258	130.40	56.8	24.4	4
18	140	5,209	18,416	131.50	57.3	24.6	5
19	120	5,209	15,525	129.37	59.2	24.2	6
20	120	6,209	15,347	127.90	47.6	23.8	4

No. of test.	Cut-off, per Cent. of Stroke.					Release, per Cent. of Stroke.				
	Right side.		Left side.		Average.	Right side.		Left side.		Average.
	Head end.	Crank end.	Head end.	Crank end.		Head end.	Crank. end.	Head end.	Crank end.	
1	9	10	11	12	13	14	15	16	17	18
1	18.6	16.5	20.9	18.5	18.62	66.5	64.8	69.1	66.0	66.60
2	26.0	24.5	29.7	27.5	26.92	72.5	71.0	74.0	71.5	72.25
3	34.8	33.5	38.8	38.0	36 27	77.8	76.0	78.2	76.8	77.20
4	45.5	44.0	50.5	46.8	46.70	81.5	80.1	82.9	82.8	81.82
5	55.8	53.0	58.1	55.2	55.52	85.0	84.8	86.0	86.1	85.47
6	77.0	75.5	79.8	77.0	77.32	94.0	93.2	94.9	94.5	94.15
7	18.6	16.5	20.9	18.5	18.62	66.5	64.8	69.1	66.0	66.60
8	26.0	24.5	29.7	27.5	26.92	72.5	71.0	74.0	71.5	72.25
9	34.8	33.5	38.8	38.0	36 27	77.8	76.0	78.2	76.8	77.20
10	45.5	44.0	50.5	46.8	46.70	81.5	80.1	82.9	82.8	81.81
11	55.8	53.0	58.1	55.2	55.52	85.0	84.8	86.0	86.1	85.47
12	77.0	75.5	79.8	77.0	77.32	94.0	93.2	94.9	94.5	94.15
13	26.0	24.5	29.7	27.5	26.92	72.5	71.0	74.0	71.5	72.25
14	34.8	33.5	38.8	38.0	36.27	77.8	76.0	78.2	76.8	77.20
15	45.5	44.0	50.5	46.8	46.70	81.5	80.1	82.9	82.8	81.82
16	34.8	33.5	38.8	38.0	36.27	77.8	76.0	78.2	76.8	77.20
17	45.5	44.0	50.5	46.8	46.70	81.5	80.1	82.9	82.8	81.82
18	55.8	53.0	58.1	55.2	55.52	85.0	84 8	86.0	86.1	85.47
19	62.0	59.1	65.3	63.0	62.35	88.0	87.5	88.8	89.0	88.32
20	45.5	44.0	50.5	46.8	46.70	81.5	80.1	82.9	82.8	81.82

Number of test.	Beginning of Compression, per Cent. of Stroke.					Barometric pressure, pounds.	Pressures above Atmosphere.		
	Right side.		Left side.		Average.		Boiler.	Dry-pipe.	
	Head end.	Crank end.	Head end.	Crank end.					
1	19	20	21	22	23	24	25	26	
1	55.7	56.1	55.0	46.5	53.32	14.54	128.9	104.4	
2	46.2	46.5	40.2	38.0	42.72	14.39	129.8	76.0	
3	38.2	36.6	32.5	31.0	34.57	14.66	126.8	62.0	
4	31.2	29.7	25.7	25.6	28.05	14.55	125.5	48.6	
5	25.1	21.5	21.0	19.7	21.82	14.54	128.7	43.0	
6	10.6	9.0	8.6	8.0	9.05	14.60	129.7	32.1	
7	55.7	56.1	55.0	46.5	53.32	14.42	128.4	117.8	
8	46.2	46.5	40.2	38.0	42.72	14.45	129.6	89.0	
9	38.2	36.6	32.5	31.0	34.57	14.60	130.3	70.0	
10	31.2	29.7	25.7	25.6	28.15	14.43	130.3	58.9	
11	25.1	21.5	21.0	19.7	21.82	14.44	127.7	48.0	
12	10.6	9.0	8.6	8.0	9.05	14.37	129.7	33.9	
13	46.2	46.5	40.2	38.0	42.72	14.40	130.0	126.1	
14	38.2	36.6	32.5	31.0	34.57	14.64	129.6	97.3	
15	31.2	29.7	25.7	25.6	28.05	14.56	130.4	89.21	
16	38.2	36.6	32.5	31.0	34.57	14.55	129.3	118.0	
17	31.2	29.7	25.7	25.6	28.05	14.35	130.2	105.3	
18	25.1	21.5	21.0	19.7	21.82	14.46	128.0	91.0	
19	20.0	18.0	17.1	16.0	17.77	14.33	123.0	79.3	
20	31.2	29.7	25.7	25.6	28.05	14.23	124.0	114.0	

Number of test.	Pressures above Atmosphere.									
	Initial.					At Cut-off.				
	Right side.		Left side.		Average.	Right side.		Left side.		Average.
	Head end.	Crank end.	Head end.	Crank end.		Head end.	Crank end.	Head end.	Crank end.	
1	27	28	29	30	31	32	33	34	35	36
1	98.4	99.3	101.9	102.8	100.8	84.4	86.0	88.6	84.0	85.7
2	75.7	75.7	76.9	76.2	76.1	61.1	61.1	62.1	60.6	61.2
3	62.7	60.3	62.9	62.6	62.1	47.9	47.1	51.5	49.3	48.9
4	48.7	46.4	47.9	48.5	47.8	38.7	38.7	40.4	40.8	39.6
5	43.2	41.9	43.0	42.7	42.7	35.5	35.5	36.6	37.1	36.2
6	22.6	31.3	32.4	31.5	31.9	29.5	30.2	30.7	29.2	29.9
7	106.4	106.2	113.3	113.3	109.8	87.1	88.4	93.4	87.8	84.1
8	88.2	85.9	88.0	85.2	86.8	65.4	64.1	66.9	63.9	65.0
9	70.2	68.6	70.6	69.4	69.7	52.8	51.0	54.1	51.6	52.4
10	58.9	59.1	59.3	58.4	58.9	43.3	43.2	43.8	43.7	43.5
11	47.9	47.5	47.8	47.0	47.5	36.2	37.6	36.5	37.0	36.8
12	34.2	32.2	32.4	33.0	32.9	30.3	29.0	29.8	29.0	29.5
13	116.1	115.6	119.2	119.6	117.6	101.6	99.6	101.6	99.5	100.5
14	98.1	96.0	98.3	99.2	97.9	80.9	79.3	81.1	78.9	80.1
15	88.2	87.6	88.3	90.0	88.5	71.7	72.3	72.5	73.9	72.6
16	109.3	110.0	111.3	115.5	111.5	84.3	85.7	87.4	83.4	85.2
17	100.8	97.9	100.8	101.2	100.1	76.5	76.3	78.3	78.1	77.3
18	87.9	85.1	87.4	86.6	86.8	68.2	66.1	69.4	70.1	68.6
19	79.8	77.7	77.0	76.8	77.8	65.1	64.7	63.8	64.1	64.7
20	111.4	110.0	114.0	111.9	111.8	87.2	86.5	89.3	87.8	87.7

Number of test.	PRESSURES ABOVE ATMOSPHERE.									
	At Release.					At Beginning of Compression.				
	Right side.		Left side.		Average.	Right side.		Left side.		Average.
	Head end.	Crank end.	Head end.	Crank end.		Head end.	Crank end.	Head end.	Crank end.	
1	37	38	39	40	41	42	43	44	45	46
1	21.5	20.8	23.4	22.7	22.1	1.5	1.4	1.5	1.9	1.6
2	18.3	16.7	20.3	18.6	18.5	1.4	1.4	1.7	1.9	1.6
3	18.1	17.7	21.2	19.8	19.2	1.7	1.3	2.8	1.6	1.8
4	17.4	17.4	20.1	18.8	18.4	1.5	1.5	2.8	1.9	1.9
5	19.3	18.7	21.1	19.4	19.6	1.7	1.6	2.4	1.6	1.8
6	21.4	21.1	23.8	20.1	21.6	1.4	1.8	3.3	1.3	1.9
7	22.9	22.1	25.4	23.9	23.6	2.4	2.4	2.3	2.9	2.5
8	20.4	18.3	21.7	17.5	19.5	3.6	2.7	2.9	1.4	2.6
9	19.2	18.1	22.8	20.8	20.2	3.2	3.1	3.7	3.4	3.3
10	20.3	19.8	21.9	20.2	20.5	3.4	3.2	3.9	2.8	3.3
11	19.9	19.3	20.8	18.9	19.7	3.2	3.1	3.7	2.0	3.0
12	22.2	20.6	22.4	20.2	21.3	2.7	2.7	3.5	2.5	2.8
13	36.4	33.5	38.8	36.5	36.3	1.9	2.0	2.2	2.3	2.1
14	31.6	32.6	35.9	33.6	33.4	1.7	1.6	2.2	2.7	2.0
15	37.2	36.5	39.7	37.3	37.7	1.7	2.6	2.5	2.5	2.3
16	34.9	34.5	38.8	36.0	36.3	4.5	4.5	5.5	5.2	4.9
17	38.6	38.5	43.3	39.5	40.0	4.5	4.4	4.9	3.8	4.4
18	41.9	38.6	43.1	40.7	41.1	4.6	4.5	5.3	4.3	4.7
19	43.6	40.8	43.1	41.6	42.3	5.0	4.9	5.0	4.5	4.8
20	46.4	44.8	49.8	45.4	46.6	4.9	4.9	6.1	4.7	5.1

Number of test.	PRESSURES ABOVE ATMOSPHERE.					MEAN EFFECTIVE PRESSURE.				
	Least Back.					Right side.		Left side.		Average.
	Right side.		Left side.		Average.	Head end.	Crank end.	Head end.	Crank end.	
	Head end.	Crank end.	Head end.	Crank end.						
1	47	48	49	50	51	52	53	54	55	56
1	0.8	0.8	1.1	0.3	0.7	26.5	26.0	33.5	30.0	29.0
2	0.5	0.3	0.1	0.5	0.3	26.1	25.3	31.6	29.3	28.0
3	0.7	1.1	2.0	1.2	1.2	27.5	27.4	32.3	30.5	29.4
4	0.8	1.1	2.3	1.9	1.5	26.8	25.9	28.6	28.7	27.5
5	1.0	1.4	1.4	1.5	1.3	27.8	27.8	29.1	29.5	28.5
6	1.0	1.9	2.4	1.0	1.6	27.3	27.3	27.1	27.6	27.3
7	1.5	1.4	1.8	1.5	1.5	28.2	26.9	36.3	32.7	31.0
8	1.6	1.2	1.9	0.8	1.4	27.5	26.2	33.4	31.3	29.9
9	1.3	1.3	1.5	1.7	1.4	28.2	26.7	33.4	32.4	30.2
10	1.4	1.6	1.5	1.8	1.6	29.8	30.4	33.5	32.9	31.6
11	1.8	1.7	1.5	1.8	1.7	28.6	28.9	30.6	30.2	29.5
12	2.3	2.5	2.9	2.5	2.5	27.5	26.6	27.2	27.4	27.2
13	1.9	1.9	1.1	1.2	1.5	50.1	47.5	57.7	55.2	52.6
14	0.4	1.1	0.5	1.3	0.8	47.9	48.2	55.7	54.1	51.5
15	4.5	2.5	2.0	2.0	2.0	54.5	53.2	59.0	58.0	56.2
16	3.6	3.7	3.5	3.3	3.5	50.7	50.7	58.8	56.7	54.2
17	3.8	4.0	3.9	2.8	3.6	56.1	55.1	61.9	60.4	58.4
18	4.3	4.2	3.9	3.7	4.0	56.6	55.7	60.3	59.1	57.9
19	4.5	4.6	4.0	3.7	4.2	55.6	54.3	57.5	56.6	56.0
20	4.9	4.9	5.0	4.4	4.8	63.1	62.9	69.5	66.1	65.4

Number of test.	Indicated Horse-power.					Fuel.		
	Right side.		Left side.		Total.	Kind of coal.	Pounds of dry coal.	Pounds of dry ash.
	Head end.	Crank end.	Head end.	Crank end.				
1	57	58	59	60	61	62	63	64
1	29.78	28.27	32.75	31.58	128.38	Brazil Block	1,833	373
2	28.41	26.68	34.44	30.94	128.47	"	1,659	182
3	30.08	29.43	35.81	32.77	128.09	"	1,598	303
4	29.17	27.30	30.02	30.26	117.75	"	1,910	177
5	30.49	29.54	31.92	31.35	124.30	"	2,245	298
6	30.04	29.09	29.82	29.26	118.21	"	2,631	180
7	48.95	45.24	63.07	55.11	212.37	"	2,699	274
8	48.37	44.80	59.03	55.50	205.70	"	2,838	384
9	49.70	45.69	59.09	55.45	209.93	"	3,014	316
10	52.73	52.15	59.26	56.47	220.61	"	3,305	310
11	50.42	49.45	63.86	51.58	205.31	"	3,287	270
12	48.46	45.41	41.87	46.77	188.51	"	4,193	371
13	53.87	49.48	62.04	57.51	222.90	"	2,491	310
14	53.10	51.81	61.78	58.16	224.85	Brazil Lump	2,893	603
15	60.75	57.48	63.63	62.70	244.56	Brazil Block	3,368	277
16	94.81	91.87	110.06	102.74	399.48	"	4,633	402
17	100.59	95.87	110.91	104.86	412.23	"	4,847	273
18	102.30	97.50	108.95	103.03	412.28	"	5,278	313
19	98.97	93.58	102.32	97.63	392.51	"	5,132	308
20	110.98	107.27	122.29	112.62	453.16	"	4,979	439

Number of test.	Fuel.					
	Pounds of coal minus pounds of ash.	Pounds of combustible by analysis. [Pounds of coal × .8112.]	Pounds of sparks in smoke-box.	Pounds of coal per indicated horse-power per hour.	Pounds of coal per mile run.	Pounds of coal per foot of grate surface per hour.
1	65	66	67	68	69	70
1	1,460	1,487	25	4.76	40.21	39.91
2	1,477	1,345	7	4.64	37.33	31.60
3	1,295	1,461	19	4.69	35.39	34.32
4	1,733	1,549	21	5.40	45.06	36.37
5	1,947	1,821	38	6.02	50.22	42.76
6	2,451	2,134	78	7.42	58.60	50.11
7	2,625	2,188	47	4.23	37.82	51.41
8	2,454	2,302	34	4.57	39.46	54.06
9	2,698	2,445	56	4.79	41.87	57 46
10	2,985	2,681	79	5.00	45.8	62.94
11	3,017	2,666	136	5.34	45.77	62.61
12	3,822	3,401	157	7.40	58.39	79.84
13	2,181	2,021	53	3.73	56.85	47.45
14	2,290	.....	113	.....	.....	.....
15	3,091	2,732	153	4.59	74.08	64.14
16	4,231	3,758	329	4.99	78.27	113.46
17	4,574	3,932	397	5.04	36.54	118.71
18	4,965	4,281	257	5.49	92.13	129.26
19	4,824	4,163	289	6.68	106.23	146.62
20	4,540	4,039	633	5.49	104.69	142 00

Number of test.	Draft in inches of water.	Indicated horse-power per foot of grate surface.	Temperature in smoke-box, degrees F.	Water and Steam.				
				Temperature of feed water, degrees F.	Pounds of water delivered to boiler.	Pounds of steam lost from boiler.	Pounds of steam supplied engine.	Per cent. of priming of steam in boiler.
1	71	72	73	74	75	76	77	78
1	0.86	7.34	590*	51.4	11,890	219	11,671	0.90
2	0.76	6.88	585*	51.1	11,068	165	10,903	1.25
3	0.85	6.31	589*	49.0	12,158	140	12,018	0.97
4	0.77	6.72	586*	48.8	12,630	117	12,513	0.89
5	0.97	7.10	595*	48.0	13,783	106	13,677	0.81
6	1.32	6.75	609*	49.7	16,782	87	16,695	0.78
7	1.35	12.13	615	52.9	18,699	242	18,456	1.16
8	1.34	11.75	612*	52.8	18,196	189	18,007	0.90
9	1.39	11.99	617*	51.4	19,256	154	19,102	0.94
10	1.58	12.60	622*	52.5	21,021	133	20,888	0.72
11	1.73	11.73	628*	52.8	22,941	115	22,826	0.82
12	2.18	10.77	655*	52.5	25,321	88	25,233	1.00
13	1.80	12.73	635*	49.4	18,156	258	17,898	0.97
14	1.87	12 85	637*	49.5	19,095	205	18,890	0.98
15	2.00	13.96	648	50.5	22,018	190	21,828	1.10
16	3.34	22.74	710	51.5	24,466	189	24,277	1.01
17	3.56	23.56	760	51.5	26,688	172	26,516	1.10
18	3.80	23.56	792	52.6	28,694	150	28,444	0.80
19	4.30	21.92	825*	56.0	23,125	105	25,185	1.00
20	4.70	25.90	787	50.5	25,795	157	25,638	....

Number of test.	Water and Steam.						British Thermal Units.	
	Per cent. of priming in dry-pipe.	Degrees superheat of steam in dry-pipe, degrees F.	Pounds of water per pound of coal.	Equivalent evaporation from and at 212 degrees.	Pounds of steam supplied engine, per revolution, by tank.	Pounds of steam supplied engine by tank, per indicated horse-power per hour.	Taken up by each pound of water delivered to boiler.	Taken up by boiler per hour.
1	79	80	81	82	83	84	85	86
1	0.12	0.	6.49	7.86	0.7942	30.24	1,161.19	4,639,139
2	0.	4.73	6.67	8.10	0.7630	30.13	1,160.76	4,277,200
3	0.	11.40	6.74	7.90	0.8280	31.28	1,164.80	4,723,600
4	0.	22.50	6.61	7.97	0.8770	35.40	1,164.90	4,906,483
5	0.	24.91	6.13	7.40	0.9520	36.67	1,166.41	5,354,134
6	0.	35.80	6.37	7.71	1.1590	47.07	1,165.72	6,523,126
7	0.58	0.	6.42	8.31	0.8051	28.97	1,158.97	7,043,200
8	0.	0.	6.41	7.61	0.7790	29.18	1,161.52	7,052,527
9	0.	8.14	6.34	7.63	0.8260	30.33	1,162.29	7,455,800
10	0.	18.39	6.36	7.40	0.9011	31.56	1,163.54	8,144,666
11	0.	21.89	6.98	8.13	0.9896	37.06	1,161.39	8,878,200
12	0.	30.56	6.04	7.23	1.0939	44.62	1,161.50	9,799,300
13	0.87	0.	7.29	8.78	1.2714	26.77	1,163.22	7,743,175
14	0.10	0.	.....	.....	1.3648	29.48	1,163.63	7,406,200
15	0.	0.	6.54	7.87	1.4440	30.04	1,162.30	8,530,433
16	0.80	0.	5.28	6.35	1.2740	24.97	1,161.86	12,181,000
17	0.65	0.	5.50	6.60	1.4523	27.57	1,161.19	12,902,000
18	0.10	0.	5.44	6.57	1.5500	29.62	1,164.77	14,326,000
19	0.	0.	4.92	5.89	1.6222	32.08	1,156.30	17,505,600
20	....	..	5.18	6.26	1.6705	28.29	1,167.20	15,052,161

Number of test.	British Thermal Units.			Pounds of steam by indicator.				
				At Cut-off.				
				Right side.		Left side.		Per revolution.
	Taken up by boiler per pound of coal.	Taken up by boiler per horse-power per hour.	Taken up by steam used by engine per horse-power per hour.	Head end.	Crank end.	Head end.	Crank end.	
1	87	88	89	90	91	92	93	94
1	7,592	36,135	35.400	.19842	.18665	.19988	.19510	.78000
2	7,915	35,494	34,862	.19460	.18540	.22140	.19880	.80020
3	7,859	36.878	36,439	.20406	.19318	.24559	.21990	.86275
4	7,698	41,616	41,255	.22386	.21411	.24850	.22489	.91168
5	7,156	43.082	42,757	.24401	.22951	.25568	.24414	.97355
6	7,438	55,183	54,878	.28844	.28101	.30627	.27845	1.15417
7	8,029	34,018	33,552	.20319	.19000	.23700	.20172	.83191
8	7,445	34,240	33,847	.20527	.19245	.23432	.20709	.83913
9	7,366	35.518	35,253	.21795	.20473	.24538	.22587	.89516
10	7,383	36.918	36,688	.23534	.22518	.26275	.23755	.96084
11	8,106	43,258	43,041	.24928	.23917	.25912	.24355	.98911
12	7,011	51,985	51,800	.21127	.27238	.29928	.27648	1.13941
13	8,481	31.567	31,170	.29111	.27259	.32687	.29390	1.18453
14	....	34,657	34,303	.30295	.28630	.33484	.31299	1.23708
15	7,598	35,256	34,945	.34259	.32822	.38233	.35229	1.40543
16	6,120	30,608	28,943	.31240	.30410	.35450	.32680	1.29160
17	6,392	32,216	32,007	.35910	.34320	.40520	.36570	1.47300
18	6,331	34,750	34,498	.38860	.35840	.41370	.38670	1.55220
19	5,698	37,250	37,095	.41471	.38608	.42876	.40374	1.63329
20	6,046	33,217	33,020	.38105	.37895	.44961	.40228	1.61189

Number of test.	Pounds of steam shown by indicator.									
	At Release.					At Beginning of Compression.				
	Right side.		Left side.		Per revolution.	Right side.		Left side.		Per revolution.
	Head end.	Crank end.	Head end.	Crank end.		Head end.	Crank end.	Head end.	Crank end.	
1	95	96	97	98	99	100	101	102	103	104
1	.20943	.19655	.22906	.20934	.84438	.08351	.08220	.08363	.07201	.32136
2	.20600	.19320	.26130	.20140	.86190	.07048	.06963	.06474	.06081	.26571
3	.21921	.20755	.24158	.22162	.88998	.06214	.05824	.05900	.05158	.23096
4	.22347	.21518	.24674	.22993	.91665	.05200	.04960	.04932	.04505	.19597
5	.24388	.23498	.26136	.24279	.98298	.04480	.04163	.04270	.03718	.16631
6	.28479	.27365	.30769	.26876	1.13489	.02571	.02904	.02658	.02184	.09705
7	.21689	.20274	.22562	.21523	.86048	.08774	.08565	.08722	.07557	.33618
8	.21853	.19738	.23270	.19566	.84727	.08017	.07529	.06953	.05913	.28412
9	.22531	.20600	.24937	.22702	.90790	.06765	.06325	.06127	.05698	.25085
10	.24184	.23017	.25786	.23786	.96773	.05767	.05445	.05191	.04753	.21147
11	.24853	.23643	.26107	.23862	.98465	.04840	.04526	.04463	.03954	.17784
12	.28900	.26860	.29456	.26791	1.12007	.02826	.02632	.02631	.02342	.10438
13	.31132	.28315	.29930	.30193	1.19570	.07259	.07205	.07515	.07004	.28983
14	.30326	.29711	.33600	.30410	1.24047	.06226	.05901	.05659	.05401	.23202
15	.35188	.33442	.37528	.34348	1.40506	.05300	.05318	.04863	.04034	.19521
16	.32280	.30740	.35660	.31760	1.30440	.07218	.06881	.06640	.06215	.26754
17	.35870	.34500	.39750	.36060	1.46170	.06085	.05771	.05463	.05003	.22321
18	.39470	.36440	.40710	.38240	1.55110	.05222	.04860	.04860	.04291	.19233
19	.41911	.38891	.42612	.39876	1.63310	.04514	.04189	.04170	.03776	.16649
20	.40776	.38477	.44023	.40939	1.74216	.06299	.05848	.05474	.05048	.22670

Number of test.	Reëvaporation per revolution.	Reëvaporation per horse-power per hour.	Condensation per revolution.	Pounds of mixture in cylinder per revolution.	Per cent. of mixture accounted for as steam at cut-off.	Dynamometer Record.				
						Tractive horse-power.	Friction of engine in horse-power.	Friction of engine, per cent. of indicated horse-power	Dynamometer work in foot tons per pound of steam by tank.	Dynamometer work in foot tons per pound of dry coal.
1	105	106	107	108	109	110	111	112	113	114
1	.0643	2.450	0	1.1156	69.92	106.03	22.35	17.41	26.90	171.3
2	.0617	2.437	0	1.0287	77.77	103.05	17.43	14.47	28.07	185.1
3	.0272	1.028	0	1.0590	81.40	104.72	23.37	18.24	25.82	172.4
4	.0049	0.201	0	1.0733	84.96	102.89	14.86	12.62	24.38	159.8
5	.0094	0.364	0	1.1183	87.08	103.70	20.60	16.57	22.45	132.0
6	0	0	0.0193	1.2510	92.26	103.96	14.25	12.05	18.49	117.4
7	.0285	1.028	0	1.1412	72.90	165.51	46.85	22.06	26.63	182.1
8	.0081	0.305	0	1.0631	78.93	166.79	38.91	18.92	27.50	174.5
9	.0125	0.460	0	1.0769	83.14	166.95	42.97	20.47	25.96	164.5
10	.0069	0.241	0	1.1126	86.35	167.44	53.17	24.10	23.58	150.0
11	0	0	0.0045	1.1675	84.73	166.52	38.79	18.89	21.67	150.4
12	0	0	0.0193	1.1983	95.08	166.52	21.97	11.65	19.64	117.9
13	.0111	0.235	0	1.5612	75.87	200.83	22.06	9.89	33.33	239.4
14	.0034	0.073	0	1.6018	77.22	209.28	15.56	6.92	31.52	223.9
15	0	0	0.0004	1.6898	83.17	210.50	34.06	13.92	28.64	185.6
16	.0068	0.135	0	1.5385	84.35	353.90	44.09	11.08	33.53	197.1
17	0	0	0.0113	1.6755	87.92	338.36	73.87	17.92	29.47	161.2
18	0	0	.0011	1.7423	89.02	341.19	71.09	16.90	27.60	149.0
19	0	0	.0036	1.8265	89.60	335.67	56.84	14.82	26.37	129.6
20	.1303	2.206	0	1.8972	84.90	395.00	57.62	12.70	30.24	156.6

Number of test.	Temperature of laboratory.	Assumed Performance.			
		Equivalent evaporation from and at 212°.	B. T. U. taken up by boiler per pound of coal.	Pounds of coal per indicated horse-power per hour.	Dynamometer work in foot tons per pound of coal.
1	115	116	117	118	119
1	69	7.90	7,630	4.73	172.2
2	63	8.00	7,726	4.59	182.8
3	71	7.89	7,620	4.84	172.2
4	67	7.99	7,717	5.39	160.2
5	67	7.85	5,581	5.68	140.0
6	62	7.11	6,867	8.04	108.3
7	74	7.57	7,311	4.65	165.9
8	71	7.58	7,321	4.68	173.8
9	72	7.53	7,272	4.77	162.3
10	61	7.42	7,166	5.11	150.4
11	62	7.34	7,089	6.10	135.8
12	80	7.13	6,883	7.55	116.3
13	61	7.32	7,064	4.47	199.7
14	53	....	....	....	.....
15	58	7.10	6,857	5.14	167.4
16	67	6.67	6,441	5.98	207.0
17	71	6.60	6,374	5.06	161.2
18	75	6.53	6,307	5.51	147.9
19	64	6.35	6,133	6.07	139.7
20	64	6.24	6,027	5.50	156.1

The work involved in getting the data into form for publication has absorbed so large a share of the time which the writer had allotted to the preparation of this paper, that a careful study of all the results has been impossible; hence no extended discussion of them can be presented at this time. There are, however, a few points to which reference may be made.

The per cent. of steam which is accounted for by the indicator, for all tests, is large. For tests at short cut-off, this doubtless is due to the early compression; and for tests at longer cut-off, to the relatively low range of cylinder temperature and to the superheating of the steam at the pressure at which it is supplied to the engine. Thus, as the cut-off is increased, the effect of compression is diminished, but this loss of effect is more than compensated for by the action of the throttle in reducing the initial pressure of the steam, and thereby increasing its dryness, and in some cases in superheating it.

This statement will also serve, in part, to explain the small difference between the amount of steam shown at cut-off and that shown at release. For the shortest cut-off, there is a little reëvaporation; the amount decreases as the cut-off is lengthened until it disappears and condensation occurs. The change in all cases is slight. Change of speed does not affect, materially, the cylinder condensation.

The record of steam consumption will be reassuring to those who have so long kept their faith in the much-maligned locomotive. It is clear that, when given a fair chance, its performance will compare favorably with that of any non-condensing, single-expansion engine. The best record shown is that of 30,608 B. T. U., or 24.97 pounds of steam per horse-power per hour, obtained from Test No. 16. This test gives also 33.53 foot-tons of work at the draw-bar for each pound of steam, or 197.15 foot-tons per pound of coal. Curves showing steam consumption for the several series are given in Fig. 323.

With 2,600 pounds draw-bar stress, when the speed is increased from 15 miles to 24 miles, there is a decided gain in the steam consumption per horse-power per hour, though the per cent. of steam shown by the indicator is slightly less at the higher speed. With 5,200 pounds draw-bar stress, when the speed is increased, there is also gain, though less than in the former case, and under the latter conditions the steam

accounted for by the indicator is higher for the tests showing the greater economy.

A comparison of tests made with the same speed and cut-off, but with a difference in load, will show how the performance suffers from the effect of an underload.

In all tests a difference of valve action produces an unequal division of work between the cylinders. The difference amounts to from 2 to 10 per cent. of the whole indicated power of the engine, a fact which will prove suggestive to those who would test locomotives by applying the indicator to one side only. The exhaust of the engine is not especially irregular.

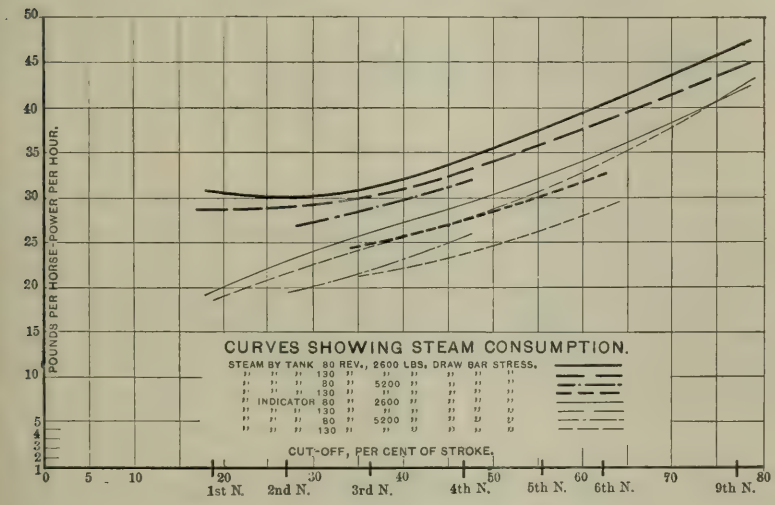


FIG. 323.

The friction of the engine, which, in the present case, includes the friction of the mechanism only, appears irregular, and for several tests it is very large. This must be accounted for either on the score of variation in the condition of lubrication, or of faults in the work. As concerning the former, it may be said that the crank-pins and the rear axle-box on the left side ran warm for some of the tests, and, on two occasions, the right piston-rod was hot for a few minutes. These conditions, all varying with the different tests, may account for the variation of friction recorded, though it is possible that the explanation is to be sought elsewhere.

The dynamometer is known to be correct, and, with the dash-

pot removed, it responds readily to slight changes of stress along the line of the draw-bar. It is composed of simple levers, which construction would seem to insure uniform action for all tests. The locomotive drivers are directly over the centers of the supporting wheels when a line on the locomotive frame midway between the driver axles is plumb with a line on a brass plug set in the stone foundation. A tell-tale, which multiplies ten times the actual forward and backward motion of the engine, was verified several times during the progress of the tests by plumbing the engine from the foundation. Ordinary precautions having thus been taken to secure an accurate record of the draw-bar stresses, it has seemed proper, with this explanation, to include all of the results with the data of the tests, and to leave their verification to the work of another year.

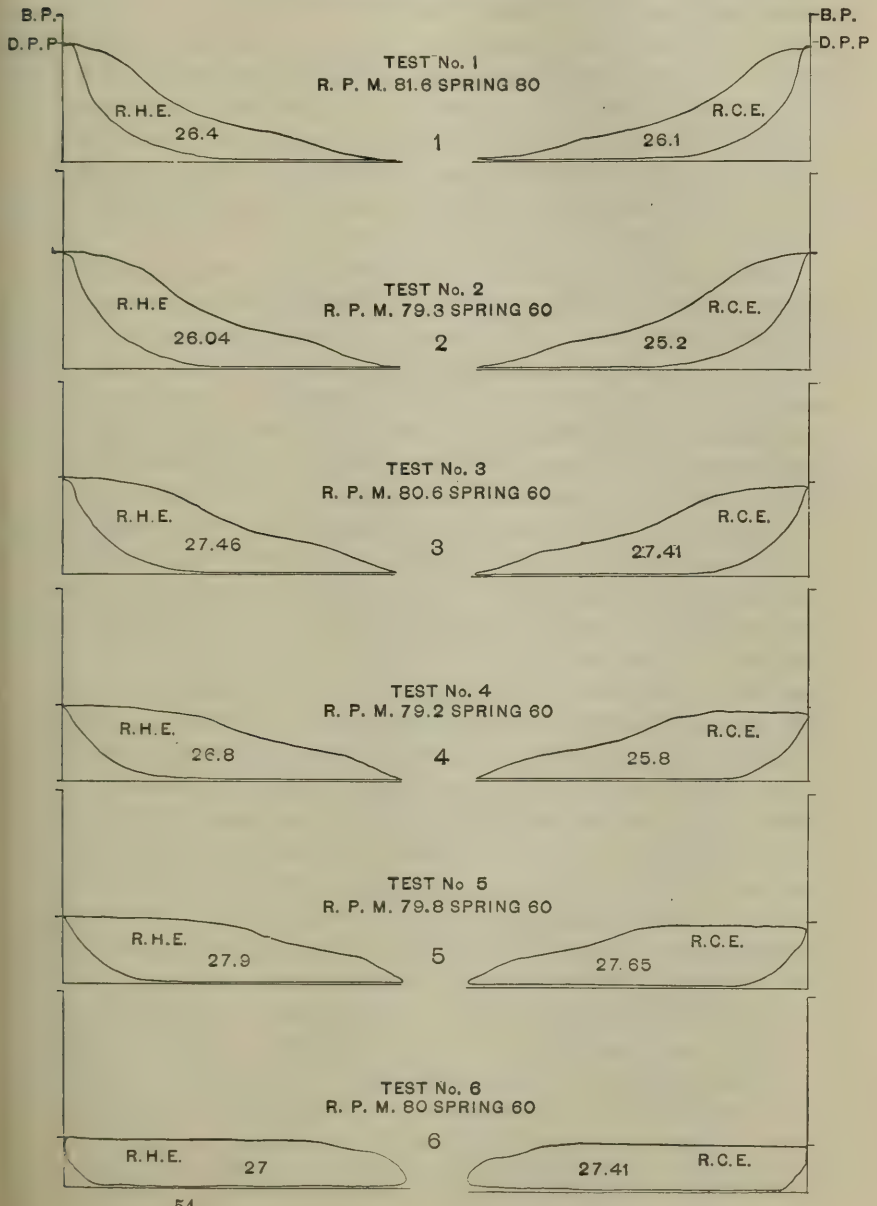
DISCUSSION.

Prof. James E. Denton.—This paper, I think, gives us for the first time a knowledge of the real economy of the locomotive since it has existed. For many years the only knowledge we had of the water consumption of locomotives came from D. K. Clark's tests in 1850. He tested two engines on a short run, taking the water from a tank; and while he got data which were pretty near the mark, the great question of cylinder condensation—that is, the whole study of the improvement in compound engines as compared with the simple engine—was found by him in one case to be practically nothing, and in the other case 14%. Everything has remained in about that condition until a very recent period, when the activity in testing the locomotives on the road has sprung up, within the last three or four years. Now it has been true, for many years, that, if they could only test a locomotive as a stationary engine, results could be obtained far more satisfactory than in any test on the road. The great difficulty in testing a stationary engine has been to control the load, to get some form of Prony brake. The water brakes which have in the last few years been applied by Professor Goss to a locomotive have demonstrated beyond a doubt that the Prony water brake, such as he has applied, can easily take care of 250 H.P. in each wheel, thus enabling the 1,000 H.P. to be put on a load and kept there with a steadiness which is surprising. There is none of the old results with a brake.

FIG. 320.

[The scale of cards is reduced from that of the originals.]

CARDS FROM RIGHT SIDE, TESTS 1 TO 6, INCLUSIVE. TESTS AT DIFFERENT CUT-OFF, LOAD AND SPEED CONSTANT.



The load is put on by a simple faucet which puts the water pressure against a disc set against the wheel, and that is touched now and then by a man who can attend it and do a lot of other things besides. So the great question which was at issue about a shop test has been thoroughly solved at Purdue University, and the tests here reported give us, I think, a real knowledge of what we may expect in the economy of a locomotive, and you will see that it is nearly as good as the best stationary engine tests. The test results here cover various speeds and various throttling at fixed pressures, but there is a good deal of ground yet to be covered. This work has simply shown us all that we can learn by tests of a locomotive in the shop.

I want to speak now of the code of tests proposed by the locomotive committee of this society, in the light of the success of Professor Goss's work. The situation to-day by the road tests of locomotives is, that it is admitted by all railroad people that the measurements of economy are highly desirable. The principal question in the investigation of locomotive data on a road test is to measure the economy. That means the water and the coal consumption. The dozen or more tests which have been made on smooth runs show that it is impossible for a locomotive to give a steady power. The various grades and the changes which occur along the track make it a fact that the range of powers vary greatly when you get through the tests and examine the collection of indicator cards. The power will vary nearly three-quarters of the maximum, and you are confronted right away with the query, What is the average power? If you average the indicator cards it is not the card which belongs to the average speed, and *vice versa*. It is impossible to study the locomotives scientifically, and to distinguish with any road tests, that I know of, the economy to be derived from the different cut-offs so as to compare the performance of two engines, on account of the fact that you cannot keep a steady load. Professor Goss's apparatus being used to test a locomotive successfully at various cut-offs, various speeds and various boiler-pressures, will give us the key with which we can interpret the road tests, besides a great deal of information which we cannot get with the road tests at all. For instance, the best road tests do not enable us to determine anything about the pressure. The variations are so great that the limit of error swallows up any difference that there may be due to boiler-pressure, and yet we believe it is there.

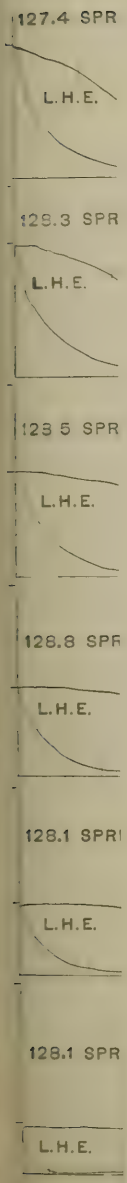

127.4 SPR
L.H.E.
128.3 SPR
L.H.E.
128.5 SPR
L.H.E.
128.8 SPR
L.H.E.
128.1 SPR
L.H.E.
128.1 SPR
L.H.E.

Fig. 321.

[The scale of cards is reduced from that of the originals.]

Cards from Tests 7 to 12, Inclusive. Tests at Different Cut-off, Load and Speed Constant.

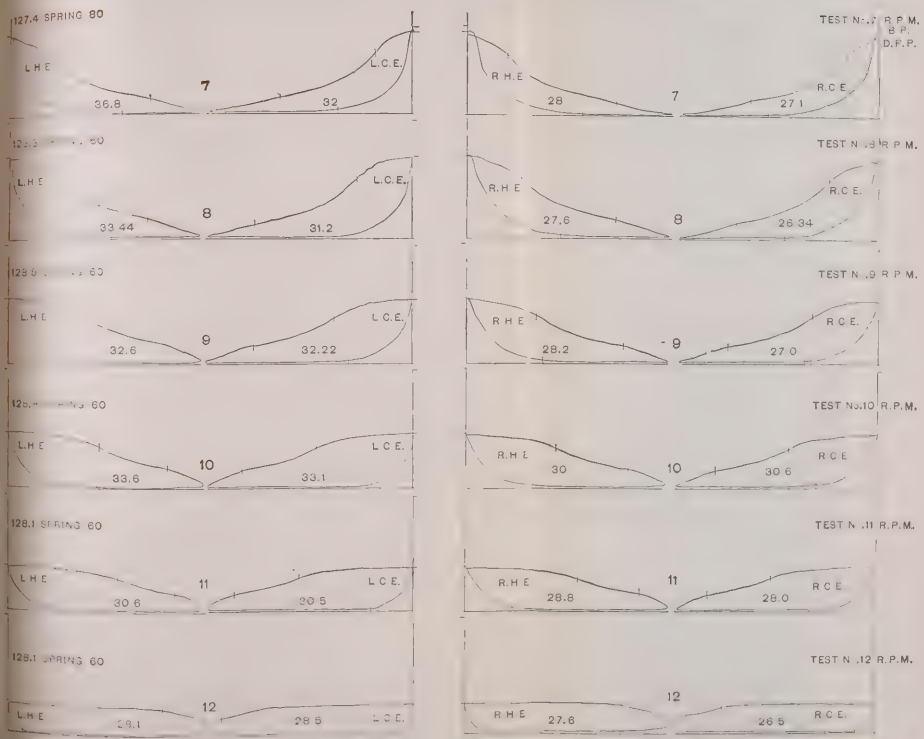
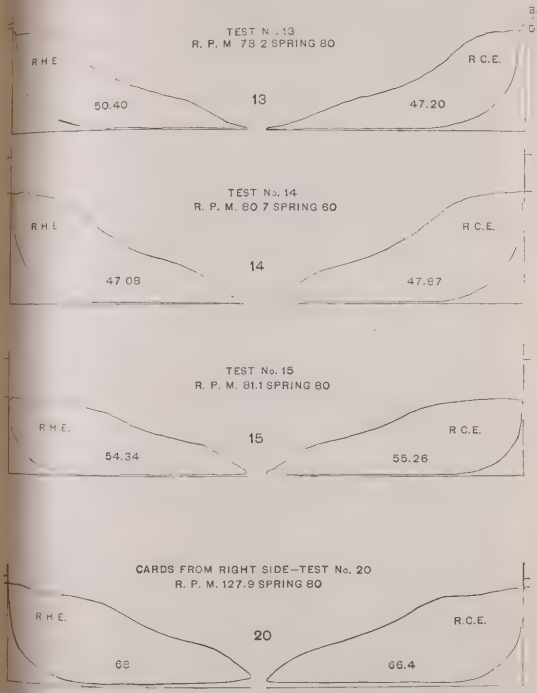


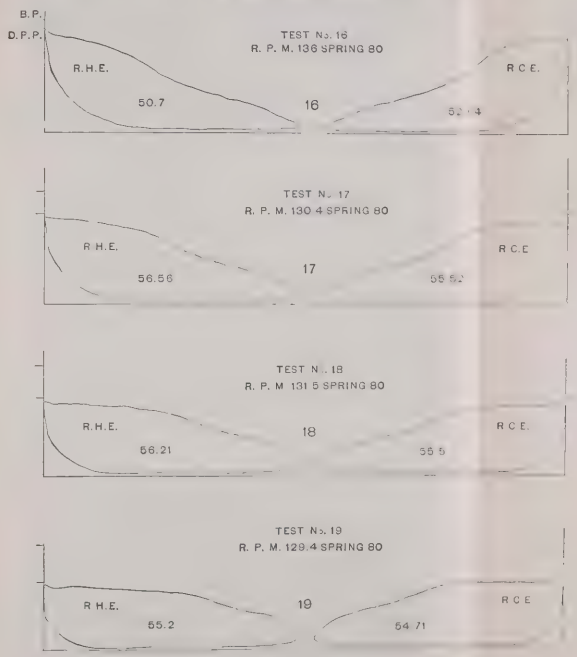
Fig. 322.

[The scale of cards is reduced from that of the originals.]

Cards from Right Side, Tests 13 to 15, Inclusive. Tests at Different Cut-off, Load and Speed Constant.



Cards from Right Side. Tests 16 to 19, Inclusive. Tests at Different Cut-off, Load and Speed Constant.



Now we can determine all this with Professor Goss's apparatus, if means are provided to use it for such a purpose.

In the economy of coal used on a locomotive, it is impossible to reduce the results to evaporation of a pound of combustible, because the ashes you get on the road are minus a large fraction of the coal blown out of the stack. That can be taken care of in this apparatus. The question of what is the maximum power and speed to be gotten from a locomotive has not been solved by a road test; there has not been any progress made with a road test, only to raise more and more inquiry on the subject.

A lot of questions of this kind are all easily solved if this apparatus can be devoted to an investigation of any one kind of engine. But, besides, we have the burning question of whether the compound locomotive is better than the simple locomotive. Of course, everybody has settled that question in his own mind for himself. We know that Mr. Dean's tests on the Old Colony have shown such a fabulous percentage that no one believes them except the people immediately interested.

Now we cannot settle any of those questions in the next five or six years. We could settle them in six months, however, if this apparatus of Professor Goss was devoted to a test of simple and compound locomotives. There will be a motion made on that subject before this meeting is over, and I want to say, to forestall criticism, that this Society should not have anything to do with competitive tests of locomotives so that a report shall discriminate between different types of locomotives; I want to say beforehand that, as I am to bring the motion up, I thoroughly agree with that; and the idea of the motion is to simply, as it were, try this mode ourselves against a simple and a compound engine, to be chosen in some way which is fair, for the purpose of the general advancement of knowledge regarding the performance of locomotives. If this Society undertakes that, there is no doubt it will be accompanied by a great deal of the glory that is always reflected by everything we do.

Sir Benjamin Baker.—I should have been heartily glad if I could have had this paper about a month ago. At that time I was for two days in the witness box in a very important case, that of the London and Northwestern Railway Company against the Manchester Ship Canal. In the construction of the canal it was necessary to carry the Northwestern Railway (three of their

main lines) over the masts of the vessels. It was provided in the Act of Parliament that they were to be compensated by the Canal Company for the extra cost of working the traffic over these grades. That opened up the whole question, What is the economy and what is the performance of locomotives? And it revealed the great difference of opinion existing among the leading locomotive engineers of Great Britain on that subject. I do not think any experiments of this thoroughness have ever been carried out for many years, if at all. I just happened to open this paper on its twenty-second page, where it gives the best record test—test No. 16—which shows that 207 foot-tons per pound of coal were done. In estimating the extra cost of hauling all these millions of tons of traffic over the masts of vessels the question arose, How many foot-tons can you do for a ton of coal? That I went into very carefully on experiments of my own, made some time ago, and having reference to the difference in the quality of the coal. I have just figured it out, and I see that the result here given, 207 foot-tons per pound of coal, is equivalent (taking account, as I say, of the evaporation of the Welsh coal used on the Northwestern road being 50% higher than that of the coal referred to in this paper) to 641,840 tons lifted one foot high for a ton of coal. Well, giving evidence for the Manchester Ship Canal, I maintained that 600,000 tons could be lifted one foot high by one ton of Welsh coal in a good Northwestern Railway locomotive. The coincidence between the figures shown in this report and my testimony, you will see, is very gratifying to me, because according to this report it ought to have been 641,840 tons, and in all my calculations I have taken at least 600,000 tons. Some of the locomotive engineers on the other side contended that there would not be more than 400,000 tons. It is quite clear from these experiments how very much the question of the quality of the coal has to do with it. I saw Mr. Webb just as I was leaving Liverpool, and he gave me some particulars about the running of the Scotch express train, and it might interest you to know that those heavy express trains, travelling about fifty miles an hour on an average, and working up some heavy grades, on an average the consumption amounts to two ounces of coal per ton per mile. They have two grades, one of seven miles long of 1 in 75, and another of six miles long of 1 in 90. In those figures the weight of the train was taken gross weight, that is, including the engine and

the tender. This train is drawn by the heaviest compound locomotive on the other side, and Mr. Webb seemed to think that the two ounces of coal per ton per mile was a good performance.

Mr. George Gibbs.—Professor Denton, in his admirable remarks on this paper of Professor Goss's, does not allude to the spirited controversy which has been going on among railroad men during the past two years in reference to shop tests *versus* road tests of locomotives. It was my fortune to be for two years a member of the Committee of the Railway Master Mechanics' Association on compound locomotives. In our first year's report we decided to present the result of an extended road test of a compound locomotive against an exactly similar simple locomotive. These tests were made possible through the generosity of the Chicago, Milwaukee and St. Paul Railway Company, and extended over about three months' time on that road, and covered about 6,000 miles of actual freight service; so that they were not only very costly, but perhaps embraced as wide a variation of working conditions as is ordinarily met with in railway service, and therefore should have given something like resulting economy in the every-day service shown by the performance sheets. When the report was presented to the Association the discussion immediately took form upon the value of road tests, some of the members stating that the service conditions were so variable in the important points that it was impossible to draw any positive conclusions as to the economy of the compound principle over the simple; others held the view that what we really wanted was the economy shown on the performance sheets, and while a single test might show an increased efficiency of 15 or 20%, if the average service performance did not confirm this the compound locomotive was of no value. This latter view is, of course, a manifestly correct one from that standpoint. The other gentlemen had also perhaps as strong grounds for their opinion, from the fact that we were trying to tell whether there was economy in the compound principle in locomotives under varying conditions of work. The conclusions arrived at by the Committee were very indefinite; the conditions were so variable that it seemed impossible to eliminate disturbing influences from the question at issue. The conclusion, however, was arrived at, that there was a substantial gain of economy in the average freight conditions, and that the compound locomotive

had fully as wide a range of economical performance as the simple locomotive. I notice in the paper to be presented by Mr. A. Von Borries, that, according to his observations, this is not the case, which only shows that two independent observers will perhaps arrive at entirely opposite opinions, due to the large number of intermediate variables entering into a road test. I, therefore, after much study of the subject, have come to the conclusion that the only way to get at certain points is by a shop test, but that shop tests cannot take the place of road tests in estimating the value of the whole machine. It seems, therefore, that in addition to this particular question there are so many other important points in locomotive economy that may be best determined by a shop test, that we should take some action as a body to assist in the formulating of tests of this kind, and should appoint a committee for this object. Professor Goss has shown that at Purdue University they have a locomotive and very complete dynamometer apparatus which is available for tests. I have understood the use of their apparatus has been offered us. At the last convention of the American Railway Master Mechanics' Association this question was discussed, and a committee was appointed to investigate locomotives in shop tests. I will therefore offer the following resolution :

"*Whereas*, The report of the Committee on a standard method for testing efficiency of locomotives has recognized the value and importance of a shop test for locomotives, and

"*Whereas*, The authorities of Purdue University are willing to put their apparatus at the disposal of a joint committee of this Society and a committee from the American Railway Master Mechanics' Association if the expenses are forthcoming, and

"*Whereas*, The American Railway Master Mechanics' Association has already appointed a committee for the purpose of prosecuting such investigation, therefore be it

"*Resolved*, That it be referred to the Council of the American Society of Mechanical Engineers to appoint a committee to coöperate with the Committee of the American Railway Master Mechanics' Association to carry out such investigation at Purdue University, to the extent of testing and reporting the efficiency of one simple and one compound locomotive."

This resolution being duly seconded was carried.

DXLIII.*

TECHNICAL EDUCATION IN THE UNITED STATES.

ITS SOCIAL, INDUSTRIAL, AND ECONOMIC RELATIONS TO OUR PROGRESS.

BY R. H. THURSTON, ITHACA, N. Y.

(Member of the Society and Past President.)

INTRODUCTORY.—The importance of the development of the technical side of education in the United States has of late years been very generally recognized, and especially by those among our educators and economists and public men who have come to see in its progress the essential basis of the future industrial and social advancement of the nation. From this point of view, the history of the inauguration of a system of technical schools in the several States, a statement of their present condition, their number, classification, aims, and methods, and of their present success and promise for the future, may prove of great interest to members of the engineering profession on both sides of the Atlantic.

Some fifteen years ago, the writer was appointed, under the authority of the legislature of the State of New Jersey and by a commission issued by the governor, a member of a board to which was assigned the duty of reporting "A Plan for the Encouragement of Manufactures of Ornamental and Textile Fabrics" in that State. As secretary of the board, also, it fell to his lot to prepare the report, including some introductory matter, and the opportunity was seized to propose to the commission some politico-economic ideas which had taken shape in his mind in connection with this department of their work. It was admitted without question that the ultimate basis of a successful system of manufactures, of whatever kind, must be a complete underlying system of technical, of trade, and of professional education. The fact was recognized that only on this foundation

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

could any nation, to-day, build up a permanent and satisfactorily efficient and varied system of industries for its people. As the writer then expressed it:* "For many years European nations have been steadily, systematically, and intelligently carrying out a policy, which is as admirable as it is successful, looking to the encouragement and support of all branches of industry in the most effective possible way, by rendering the artisan and the laborer more intelligent and better informed; not simply offering him general knowledge through a system of general education in the common or public schools, but teaching him the essential principles which underlie the practice of his art, and supplementing in trade schools this directly practical education by the still more practically useful and immediately applicable knowledge of the manipulations peculiar to his work.

"The only way in which to compete with the conditions introduced by this statesmanlike and most enlightened policy is, evidently, the introduction of a similar policy, and, if possible, a more complete and extended application of the methods dictated by it, than has been elsewhere attempted. Technical education and trade schools adapted to nearly every important branch of industry have long formed part of the European system of aid to manufactures; and it is evident that successful competition in future years is not likely to prove satisfactorily successful unless the task of overtaking our competitors in a race in which they have many years the start of us, and in which they have already acquired every advantage that such a start and the gain of experience derived by the progress of a full generation can give, is very promptly commenced and very energetically and intelligently prosecuted. Our people are, and always have been, largely dependent upon artisans imported from abroad for aid and direction in every branch of industry in which extraordinary skill, taste, or acquired knowledge of technical details is demanded. We can only become independent by supplying ourselves with the means of similarly training our own workmen."

"A plan for the encouragement of manufactures, to be effective and of lasting benefit to those industries, must include, primarily, some practical scheme of education and industrial instruc-

* Report of New Jersey State Commission, Trenton, 1878. Also *Sibley Journal of Engineering*, June, 1892: "The Demands of the State."

tion and training that shall render the working-people engaged in those branches the equals, if not the superiors, in intelligence, skill, and knowledge, of the same class in any other country. Such a plan must include a general policy of encouragement of every effort to introduce new divisions of work and to diversify existing established industries. No restricted scheme or narrow policy can be of great or permanent benefit."

In outlining a plan of general education for the "industrial classes," as they are called in the famous "Land Grant College Bill," which we owe to Senator Morrill, as the foundation of the principal part of our educational structure in the United States, the following was thought by the writer to present as complete a scheme as could safely be proposed at the time:

A GENERAL SYSTEM OF EDUCATION of the people, aiming at their preparation for the intelligent performance of their duties, and for success in their vocations, must comprehend the following elements of a complete system specially adapted to their purposes, apart from the system of education for education's sake, which was formerly considered the only education to be offered, and that only to the well-to-do among the citizens of the nation:

(1) A common school system of general education, which shall give all young children tuition in the three studies which are the foundation of all education, and which shall be administered under compulsory law, as now generally adopted by the best educated nations and states on both sides of the Atlantic.

(2) A system of special adaptation of this primary instruction to the needs of children who are to become skilled artisans, or who are to become unskilled laborers, in departments which offer opportunities for their advancement, when their intelligence and skill prove their fitness for such promotion, to the position of skilled artisans. Such a system would lead to the adoption of reading, writing, and spelling books in which the terms peculiar to the trades, the methods of operation, and the technics of the industrial arts should be given prominence, to the exclusion, if necessary, of words, phrases, and reading matter of less essential importance to them.

(3) A system of trade schools, in which general and special instruction should be given to pupils preparing to enter the several leading industries, and in which the principles underlying each industry, as well as the actual and essential manipu-

lations, should be illustrated and taught by practical exercises until the pupil is given a good knowledge of them, and more skill in conducting them. The series should include schools of carpentry, stone-cutting, blacksmithing, weaving schools, schools of bleaching and dyeing, schools of agriculture, etc., etc.

(4) At least one polytechnic school, in which the sciences should be taught and their application in the arts indicated and illustrated by laboratory work. In this school, the aim should be to give a certain number of students a thoroughly scientific education and training, preparing them to make use of all new discoveries and inventions in science and art, and thus to keep themselves in the front rank.

(5) A system of direct encouragement of existing established industries by every legal and proper means, as by the encouragement of improvement in our systems of transportation, the relief of important undeveloped industries from State and municipal taxes, and even, in exceptional cases, by subsidy. It is evident that such methods of encouragement must be adopted very circumspectly and with exceedingly great caution, lest serious abuses arise.

(6) A system of general supervision of the industries of the State by properly constituted departments of the State government. This system should comprehend, perhaps, a Bureau of Statistics, authorized, under the law creating it, to collect statistics and information relating to all departments of industry established, or capable of being established, in the State, and to publish such information and statistics in circulars for general distribution, and in a report to be made to the State legislature, annually, with the governor's message.

"The extent to which the measures here proposed may be expected to benefit the people of the State will, as a matter of course, depend upon the completeness and thoroughness of the plans adopted in carrying them into effect, the intelligence and knowledge as well as the energy of those to whom their prosecution is entrusted, and the capacity of the people to comprehend and to take advantage of the opportunity for self-improvement thus offered them, and their inclination to avail themselves of it."

THE EXTENT OF THE FIELD open to institutions founded for the purpose of meeting these great needs, by offering technical instruction, may be imagined when it is known that to educate our

people as well, in these various directions, as the most favored parts of Germany, we should have:

Twenty technical universities, having in their schools of engineering and higher technics 50 instructors and 500 pupils each.

Fifty trade schools and colleges, of 20 instructors and 300 students each.

Two thousand technical high schools, or manual-training schools, of 10 instructors and 200 pupils, each.

That is to say, there should be in the United States to-day 1,000 university professors and instructors, and 10,000 students under their tuition studying the highest branches of technical work; there should be 1,000 college professors and 15,000 pupils in technical schools, studying for superior positions in the arts; and 20,000 teachers engaged in trade and manual-training schools, instructing pupils, 400,000 in number, proposing to become skilled workmen. We have in this country 10,000,000 families, among which are at least 1,000,000 boys who should be in the latter class of schools. The cost of such education would be, per annum, about 50 cents per inhabitant additional to the present school tax, and in the shops of these schools less than $100 per student, and for total costs of higher education under $300 per annum per student. Such is the work of which so small a part, at most, can be done by existing colleges, however great the desire of the authorities to carry out the intentions of the people. Such is the somewhat intimidating comparison, also, of the condition of our country, and the more enterprising and wisely governed countries of Europe. The latter have had generations the start of us, and only the extraordinary natural advantages of our country, and the more extraordinary general intelligence and enterprise of its citizens, can possibly prevent this disadvantage under which we labor from telling fatally against us in the course of time, when the inevitable competition of the world shall affect us.

"Aside from the improved value of the engineering college as a means of technical and professional education and training, this attainment of the end, so long held in view, has this most important result: that it is now possible to clearly show to intending aspirants for degrees that, since it must be a professional school, there cannot be expected of it any considerable portion of that literary training which constitutes general education, and that this should be sought, as in the case of the study of

law, before entering the professional school. It has often happened that parents, as well as young men proposing to study for a profession, have made the serious and almost fatal mistake of assuming the possibility of securing at the same time a good general education, in English and scientific branches, at least, and a professional training, and that it is practicable to secure either an education in the professional school or a professional training in a semi-educational institution. This, experience proves, in engineering as in law, to be entirely impracticable. The small amount of general education given in any of the professional schools has little value for its purpose, while simply crippling to a more serious extent the work for which the school is especially fitted and established. The education—and as complete and as broad an education as the means of the student will permit—should be first secured and made a sound and ample foundation for his life-work; *then* the young man should take up his professional work, well prepared to appreciate it, mature, intelligent, earnest, and discriminating. The professional man, whether physician, engineer, lawyer, or divine, should give his time and thought, in early years, to the securing of the best possible education in the best possible way *first*, and, that done and well done, should next take up a professional course. The whole strength and all attention should be given first to one, then to the other, to secure highest results in either field." *

There exists, however, among the members of the profession a strong impression, one which, it must be confessed, has some justification in the experience of the past, throughout the world, that a technical school cannot be made to succeed, fully and satisfactorily, as a part of an organization including academic schools; but that in the presence of these apparently conflicting interests the school of engineering must suffer, if not absolutely fail This conviction is expressed very strongly by President Eliot, of Harvard, and still more so by the German educator, Professor Reuleaux, the head of the great technical university at Berlin, and who is by many regarded as the leader in the profession in Europe. In his address entitled "*Cultur und Technik*," he says that, "notwithstanding their intended pursuit of a strictly scientific aim, the technical schools have not concluded

* Sibley College Reports, 1892.

their peace with the universities. Even with the best of good will, none of our efforts toward a real amalgamation of the two has ever been successful." He quotes Professor Koechly, who says: "And if not side by side, at least we can fight back to back," in the great contest with ignorance and barbarism. He considers this unfortunate difference as arising from inherent differences in aim, and goes on to say that a blending of the two movements has been tried in the United States, our universities being both classic and technic, but that "the experiences hitherto gathered have not shown, so far as observation permits a judgment, that the union can be permanently maintained, or that it has furthered the interests of education in the way that legislators had anticipated." *

Says Richter: "The Spirit of the Nation and of the Age decides, and is at once the schoolmaster and the school; for it seizes on the pupil to form him with two vigorous hands and powers." It is the spirit of our age which is being felt in this modern movement toward an education of the peoples. It is coming to be that which would educate the man for his life and would train him for his work. It would give him the knowledge and the intellectual capacity needed to enable him to profit by the opportunities coming to him in his intellectual life, while, at the same time, it would prepare him to secure those opportunities and care for family and self through the exercise of his faculties in some definite and profitable department of human activity. But, as the same great mind has expressed it, "The end desired must be known before the way. All means or arts of education will be, in the first instance, determined by the ideal or archetype we entertain of it."

Such a scheme, I take it, may fairly be said to represent the form of that "new education" which is but a modification in the direction of completing the old, and a step in the organization of that system of "perfect education" for which Milton entered his eloquent plea two and a half centuries ago (1644). The new and the more complete education looks toward the perfection of a new method of making the man and the woman ready for that work which life brings to all. It aims at the betterment of citizens and nation alike, and through the same process.

As I have elsewhere remarked: The prosperity of the people

* Sibley College Reports, 1885.

of any country is dependent, primarily, upon their own industry and integrity, skill and enterprise, persistence and "pluck," and, to a considerable extent, upon the natural advantages and resources of the country itself, as determined by the character of the soil and climate, and upon the location with respect to home and foreign markets and sources of supply of raw material; but the prosperity of the nation is the greater, other things being equal, as the value of the labor of the working classes is increased, and the value of such labor is the greater as the products of industry are more generally the result of trained skill, and cultivated taste and talent employed in the so-called skilled industries. The cultivation and diversification of skilled industries, of the mechanic arts and of art-industries, is evidently mainly to be relied upon to promote the highest possible prosperity of a people. Trade education, schools of the mechanic arts and of engineering, the cultivation of industrial art, the promotion of the fine arts, in such manner as to give to the worker in every field the intelligence and skill needed to enable him to do good work, and to provide new and broadening fields of labor, free from the fatal competition that causes each worker to become the enemy of his neighbor, are the resources upon which, only, we may rely for the relief of the pressure characterizing modern civilization. Those states, and those nations, will evidently be the most successful and prosperous in which the aim of legislation, and of the educational system, is to secure the effective training of the laborer, and to give the worker in the higher fields of industry the most thorough training for his work. The accumulation of wealth can result only from our material progress, and it is only by the accumulation of wealth that the world can secure the blessings of intellectual or even moral advancement, the comforts of life and healthful luxuries. But the accumulation of wealth comes of the two lines of progress: the cheapening of all essential and destructible elements of life and civilization, and the steady and efficient application of the powers of the body and of the intellect of man to the production of permanent and essential wealth in the forms most useful to the mass of mankind. The highest duties of the state and the citizen are thus to be fulfilled by providing the opportunity to every man to give his sons and his daughters the means of making their heads and their hands of maximum service to themselves and to their neighbors, to gain means of directing the

forces of nature, and the power of utilizing their own natural ability and skill with highest efficiency. Education must be directed in such manner as to give, in the least possible time, and in the most effective way, at least a preparation for the duties of daily life, while, at the same time, so far as is practicable without interference with the more imperative work, training the scholar to become a good citizen, and to enjoy the intellectual side of existence. It is in recognition of this view of our duties that we are beginning to see manual training and a trade school system incorporated into the common school system of education of every civilized country, and technical and professional schools and colleges taking their place beside the older institutions of learning. From this time on, he who would accomplish most in either of the departments of skilled industry or in either of the branches of the great profession of engineering, must combine scientific attainments with experimental knowledge of facts and phenomena, mechanical ability, and also good judgment and taste ripened by large experience in business and familiarity with the ways of the world. It is only when manual training and trade schools are found in every town, technical schools in every city, and colleges of science and art in every State, so united—in a system that shall insure to every one the privilege of learning the scientific basis of any art, and of laboring in every or any branch of industry—as to make certain a recompense for all the zeal, intelligence, skill, and industry that the worker may exhibit, that the professions will attain their grandest development, science and art find closest and most fruitful union, and the citizen enjoy to the fullest extent all that he may rightfully demand in his pursuit of everything that life and liberty can offer him, and the most perfect happiness that can come to man. The highest skill, the most reliable labor, and the most admirable artistic talent are to be obtained only by systematic cultivation, and the new features of modern education are those which are directed to the objects above outlined.

A complete scheme of education aiming at the development of the powers of the mass of the people and the securing of the greatest possible prosperity of the nation must include the manual training school for youth, the trade school for those proposing to fit themselves for successfully pursuing industrial pursuits, and the technical and engineering schools in which the scientific development of the constructive professions is aimed at.

In the first, young people are to be taught the use of tools; in the second, the arts of carpentry, weaving, blacksmithing, stonecutting, and other industrial arts; and in the third, the greatest of all arts, that of contriving methods of turning the powers and processes of nature to the uses of man, and of inventing and designing all the mechanisms, apparatus, and structures needed in the work. The highest department of instruction, and that in which the greatest of all the institutions included in the system will take part, is the thoroughly scientific training and education of students with a view to preparing them to take advantage of all new discoveries and inventions, to thus keep themselves in the front rank among those who do the great work of the profession; it will also, while giving instruction to the ablest and best students, supply to the technical schools and colleges of the country well-taught and talented instructors, able investigators, and skilful administrators, and will aid by scientific research the development of every industry, and furnish a nucleus about which may gather the great men of the nation capable of instructing not only the youth who may come to their lecture-rooms and laboratories, but the legislators and executive officers of the government whenever they may be called upon to deal with any one of the innumerable questions affecting the national weal through its industries.

Experience has shown that systematically planned and carefully conducted schools of science and of the arts are vastly more efficient in the education and training of young people than any workshop or mill can possibly be. In them every operation may be thoroughly taught, and the learner may be familiarized with every detail without loss of time or strength on the part of either teacher or pupil. It is such a system, incorporated into the educational scheme of every European country, that has given them, notably in the case of France and Germany, such rapid growth in productive power and prosperity, and which has, for a time, threatened other nations with such serious competition. It is now recognized as an obvious principle, that in order that a nation may prosper under existing conditions of competition and cheap transportation of materials and products, the people must be so much better educated in the principles and trained in the practice of the arts in which they compete with other nations, that their marketable productions may be introduced into the markets of the world, com-

peting both in quality and in price with all that may be there encountered, and yet yield the producers better remuneration for the day's work by their ability to make a day's work more productive through the exhibition of greater skill, or the invention of better machinery, and by the exhibition of finer taste and better knowledge of art.

The modern systems of technical education are directed towards these vitally important ends; and it is perfectly evident to every intelligent citizen that the prosperity of the nation is, for the future, to be mainly dependent upon the success and rapidity with which this system is introduced throughout the land. Where there is to-day one such school as has been described, a hundred are already needed. It is difficult to realize the rate at which foreign nations are advancing in this direction, and how rapidly our own country is being distanced. It will demand the most earnest thought and the most energetic action on the part of those entrusted with the work of developing our educational system to prevent a very serious, if not disastrous, competition from abroad within probably the next generation. It is fortunate that the change has progressed in our own country even so far as it now has, and that its continued progress is assured.

But science and technical studies will never and ought never displace the older departments of education. As the one is absolutely needed for the material welfare of the country, the other is no less essential to intellectual prosperity and to the cultivation of a real scholarly spirit and to the growth of the æsthetic side of life, of all that makes the possession of wealth really desirable.

When the new system shall have become fully developed, it may be hoped and fully expected that it will be common, if not customary, among those who pursue science and study the professions, if engaged in construction, to secure the broad and liberal culture of the older schools before entering upon their purely professional studies. Their line of work should lead into and through the general courses, and on into the professional schools. Knowledge, discipline, training in all the humanities, may and should precede the final special preparation for the work chosen by the citizen as the means of doing most for the world and of acquiring fortune.

European nations have been for many years, for a century at

least, steadily, systematically, and intelligently carrying out the policy above outlined, and the only way in which to compete with them is evidently to adopt a similar policy, with even greater care and with, if possible, more effective methods. Technical and trade education have for so many years been a part of the European systems of aiding manufactures that we may expect it to require many years to equal, much more to overtake them in the race. The effect has long since been felt in the importation of skilled artisans and engineers from those countries to do work demanding the peculiar expertness coming of such scientific training. We have taken up our work in this direction none too early.

THE NEW EDUCATION, which is yet the old, is simply that advance in the application of these never-denied and long-admitted principles of polity and of public policy which have come to be seen to be demanded as a consequence of the progress of the age in invention, in the arts, and in our systems of industry. Reading, writing, and arithmetic were once the all-sufficient education of every class engaged in industrial pursuits. To-day a college education is insufficient to meet all the demands of some of the professions; and special schools are established in every country and in almost every city. A few years ago there were but three professions, and but three kinds of professional schools; to-day there are many both of the professions and of the schools. The old education was mainly gymnastic; the modern is both gymnastic and immediately useful in the vocations of daily life. The old university was a home for those who were called by Isaac Walton "cloisteral men of great learning"; the university of to-day is a workshop of all the arts and sciences as well as of the literatures. It is the product of a growth, not of a new planting, however, and we may reasonably hope for indefinite future improvement, and more and more splendid fruitage with the coming years.

The characteristic of the century has been the introduction of so-called technical education: the instruction of youth in those elements of industrial education which will give a training in all that is needed to make the pupil capable of doing a man's or a woman's work in the world, as a single unit in the complex system into which our lives are interwoven. The older system of education was one of primary school education for the people, high culture for the wealthy. A century ago it began to be

seen that this curriculum must be broadened in the intermediate fields, and that it should include more of science and more of culture as well for the citizen of whatever grade, and that applied science and systematic instruction in the skilled industries of highest class must be introduced by every nation that would make the most of modern developments in the arts. France and Germany were the first to take the practical initiative and to establish national schools of the literatures and the philosophies. Their statesmen were the first to see that nations could now only be made great and secure by the incorporation, with the "book learning" of earlier times, of all new sciences, and instruction in all new arts demanding system and skill; and the results of their foresight and energetic action are hardly less striking than were nearly twenty centuries earlier those of the work of what Draper called "the Scientific School of Aristotle" at Alexandria, the inauguration of which was the first and is still the grandest event in the history of education. These great statesmen saw what had been in the minds of other great men long before: that security in the mighty struggles among nations, to result in the survival of the fittest presumably, could only be insured by the systematic instruction of the people in the work of the people, and to day all nations vie with each other in this competition for the foremost place in the industrial race by expanding educational systems to meet this demand.

But the new education is but the seen expression of the principles declared by the oldest educators of all races and of all civilizations. Aristotle inspired the teachers in the "Divine School of Alexandria" with the true scientific method which is at the foundation of all progress in knowledge of whatever kind; and the great philosophers of that time and their works have been ever since the acknowledged progenitors of the modern man of science. Archimedes and Euclid, Eratosthenes and Hipparchus, led in the propagation of the systematic development, perpetuation, and diffusion of true science and useful knowledge. Ptolemy Soter founded the prototype of the modern university in its most complete and symmetrical form. That was a greater work than was ever done by the mighty warrior after whom the university was named. Archimedes was an engineer; Hero was a mechanician; Euclid was the mathematician of whom it can be said, as of no other man, his works have never been overpassed; Hypatia expounded the doctrines of the

philosophers ; Ptolemy gave origin to astronomy, and Philareus was the presiding officer of a true university. Comenius, centuries later, but dreamed of the reconstruction of this scheme ; and Milton, in his " Tractate on Education," proposing to teach all the useful branches of knowledge, and Bacon prescribing systems for the " Advancement of Learning," only presented anew the new education which was still the old.

When the Marquis of Worcester urged the inauguration of technical schools and the formation by the government of trade-schools; and when that wonderful mechanic, Vaucanson, gave his collection of models and machines and curious inventions as the beginning of the French " Conservatoire," the first of great modern schools of applied science, they were but doing their part toward the restoration to the body, from which they had been lopped during the intermediate monastic period, the right arm and hand of a symmetrical system. Des Cartes and Herbert Spencer in their studies for a better education for the modern time, and Scott Russell in his eloquent plea to the Queen for an education for the *people* of England, were merely resuscitating the long-neglected but still living ideas of Aristotle and of Plato. And a modern university, like that of the ancient Greeks, includes and presumes instruction in all knowledge that makes the life of the time and underlies necessity, comfort, and luxury, or labor, leisure, and self-improvement. The lapse of the middle ages and of our later times, until within the generation almost, was simply failure to incorporate into the old scheme the newer knowledges and the later applications of knowledge of modern life. We, to-day, in our technical schools and in our departments of applied science, are simply remedying a neglect of our predecessors, making symmetrical and complete that structure which had been left without extension and here and there in decay for so many generations ; while every phase of life was becoming richer and richer, and demanding more and more from the insufficient system.

We have, at last, once more come to see that Plato was wise in his day and generation, and for our own as well, and that the state should aid the people to secure a state university in something more than a stereotyped and crystallized form. Continuous change and steady progress must be essential characteristics of any perfect force of education. That progress must have, as its first result, the constant and perfect adaptation of the

whole university, from primary to final element, and from classical to technical and professional branches, to the requirements of every class and grade of citizen. The rich no less than the poor; the scholar and the handicraftsman alike; arts and sciences, languages and literatures, and all the philosophies, must not only find place, but must be kept in place, and the whole system continuously and always adapted to the steadily moving world.

Any real education, new or old, must be such as best prepares the man, and the woman no less, for successfully striving for all that either may fairly and rightfully hope to gain from the world and to find in life. It must cultivate the mental powers, give physical strength and endurance, supply wisdom and knowledge for application in all the fields of life-work, offer special instruction and training where needed for prosecution of those branches of industrial occupation which demand either higher education in the sciences or special knowledge of processes and methods of work such as cannot be subsequently obtained by the youth leaving his teachers behind him and going out into the world to take up his tasks, whether in the forum, on the bench, at the bar, in the pulpit, by the sick-bed, or at the table of the operating surgeon; whether he goes into art or architecture, engineering or school teaching, building steam engines or cotton machinery, railways or canals, working at the loom or at the blacksmith's fire. The aim of the framers of any state university system and its feeding and accessory departments should be to prepare for the development of all the industries, the creation of intelligence, the encouragement of good morals, and a righteous distribution of moral, material, and intellectual good to all citizens, and, as far as nature permits, in equal degree through equal opportunity. The greatest practical diversification of industries, the widest distribution of knowledge, the most equitable distribution of wealth—moral as well as material, intellectual as well as ponderable—all and equally, should be the purpose of the builders of the nation's noblest structure. It is this reconstruction of the ideas of Plato and of Milton and of all great minds since the time of Aristotle which we now see rapidly taking form around us. The real university is coming into being; the teaching of teachers, as well as the training of pupils for the real work of life, is one of the illustrations of the extent and the completeness with which the old idea has been incorporated into the new and still more perfect form in this later time.

A new education and a new civilization based upon it as the firmest foundation; perhaps, more correctly speaking, an education and a civilization one and inseparable, interwoven as warp and woof, united as the roots support and form union with the tree and its branches and their fruit—constitute the most impressive feature of modern life, and give most reason for thought and speculation to the modern philosophic historian and the student of economics. It is this modern phase of a steadily advancing progress that presents to us, who are here gathered on a supremely important occasion, most interesting material for study and most important problems.* The promotion of the best purposes and highest welfare of the nation in the directions indicated by Webster presupposes the solution of such questions as these: What is the purpose of education? How is it related to these highest interests of the people? How can we, who are more or less responsible for the proper education of the "industrial classes" especially, promote that education which will best meet the needs and the demands of the nation, and of its citizens individually? How does this duty of promoting the best education for modern times and modern life fit in with our duties as citizens and members of a fraternity in which the good of all is best consulted by aiding the individual in his endeavor to gain that life, that liberty, that freedom in the pursuit of true happiness, which is the fundamental thought of the Constitution of our Republic?

Framing the educational system of a people is a greater work than even the construction of its foreign policy or the organization of its penal code. These are the highest duties of the state, and it is in this work that patriotism, statecraft, wisdom, and honor find their noblest place. THE EDUCATION OF THE PEOPLE IS THE BUILDING UP OF A NATION. *

THE IDEAL EDUCATION would thus be such as should fit the citizen for successful pursuit of every desirable object in life, while enabling him to secure the capital needed for its complete attainment and thorough enjoyment. It would begin with the primary instruction demanded as preparatory to the studies of its later periods. The primary education would be followed by so much of secondary education, in the sense in which that term is now generally used, as should give to the youth the

* Address by the writer on "The New Education:" "Commencement" at Ohio State University, 1892.

essential elements of a truly liberal education, such as should prepare him to continually advance into the unlimited fields of human knowledge; to gain from day to day, through all his after life, more knowledge and higher learning in every division of science, literature, and art; to enter upon the philosophical study of history, the comprehension of comparative philology, of the development of literatures; of the seductive and wonderful problems of mathematics; of the no less wonderful principles and strangely beautiful phenomena of the physical sciences; the still more marvellous laws and operations of nature, as illustrated in the living creation; and, more than all, to obtain some comprehension of the moral and the intellectual, sufficient, perhaps, to gain a glimpse of that great spiritual world of which the grandest minds and the loftiest imaginations which the human race has yet produced have never yet been able to grasp more than the most infinitesimal portion. A truly liberal education (and by this I mean vastly more than a strictly classical education) fits man to walk with his Creator in every field, spiritual, intellectual, physical, which the creature's faculties are given him to explore. From this point on, the education of the youth, now becoming mature in mind and body, must be made, usually, even where not before, special. He has been given the means and has been shown the way by which to enter into his wonderful heritage of the universe. Now, because he cannot grasp all, and because he must prepare himself for such complete knowledge of a vocation and of all which is demanded for its successful prosecution, and because he may undertake a very small part of the work of the world and that in a very restricted field, he must become a specialist, and must, in this work, confine his time, thought, and labor to the acquirement of a profession or of a vocation. This must be the final period of his education; for, after entering upon his chosen life's work, he cannot usually expect to find opportunity to continue his education as an occupation. He must then buckle himself to the task, and take only such rare and short intervals for intellectual pursuits as may be given him in hours of rest and rare leisure.*

The ultimate source and fountain of the learning which will, in time, give the world its highest and best estate must be un-

* "The Nation's Great Problem:" Rose Polytechnic Institute, "Commencement" Address, 1886.

questionably the State university, possibly already prototyped in the universities of the several States, but, more probably, I imagine, by that grandest of universities which George Washington would have founded, a century ago, at the national capital, "at which the youth of the world may be proud to receive instruction." *

A national university, at the capital of the nation, amongst its already enormous stores of literature, its scientific institutions, its great museums, its concentrated and diversified and extensive faculty, both civil and official, would, if properly organized, and administered as the culminating element of the whole educational system of the nation, prove as wonderfully efficient in promoting the civilization of our time as was that great school which, two thousand years ago, gave such marvellous impetus to the ancient world. As the prophetic contemporary writer of that time asserted, addressing Washington and his colleagues in the government: "Should this plan of a Federal university be adopted, then will begin the Golden Age of the United States. While the business of education in Europe consists in lecturing upon the ruins of Palmyra and the antiquities of Herculaneum, or in dispute about Hebrew points, Greek particles, or the accent and quantity of the Roman language, the youth of America will be employed in acquiring those branches of knowledge which increase the convenience of life, lessen human misery, improve our country, promote population, exalt the human understanding, and establish domestic, social, and political happiness. This can never be effected except by our young men meeting and spending two or three years together in a national university, and afterwards disseminating their knowledge and principles through every town, county, city, and village in the United States." It was in recognition of this essential element of a complete and perfect national system of education that Washington not only worked, and wrote, and plead with Congress, but gave of his substance. He left a provisional legacy to aid in its foundation. A national university, with a system of State universities of more specialized character, and systems of primary and secondary education in the several States, each and all contributing to the great purpose common to the minds of Milton, of the Marquis of Worcester, of Vaucanson, and of Washington, each holding its

* Samuel Blodget's "Economica," p. 22; Memorial on a National University, Washington, Government Printing Office, 1892.

place and each taking its place as an element of one great continental system of education of the people, for the purposes and needs of the people, in every walk in life, constitutes a complete and perfect ideal educational system toward which every modern movement tends. As I have somewhere written before in relation to this general subject:

"Plato and every great philosopher since his day recognizes the education of the people as the chief duty of the state; Aristotle set the example of cultivating every useful branch, and the Alexandrian school set an example to the modern university. All great thinkers have urged that the technical side of life be most carefully and fully represented in the educational system; all great nations have found the prescription one leading to the advancement of every element of prosperity. A great university is at once the type, the exponent, the promoter, and the basis of all that is good and great in modern civilization; modern life is but the product of an evolution originating with life itself. Homer, Milton, and Shakespeare; Plato and Emerson; Hero, DaVinci, Watt, and Corliss; Solon, John Bright, and Henry Ward Beecher; Washington and Abraham Lincoln—these are all elementary parts of one eternal whole; their relative chronological position gauges the growth of the race. Homer's 'Iliad'; Plato's 'Republic'; Quintilian's 'Treatise'; Milton's 'Tract'; the works of Richter, of Rousseau, of Goethe, and of Herbert Spencer—all such are milestones of progress from the old education, which was the old civilization, to the new education, which is the new civilization; from all the old worlds to all the new. And, as time passes us on into the newer old, education will progress and change with the times that are coming, as it has progressed and changed with the times that are gone; but its change will be changeless in that it will always represent the latest, the highest, and the best possible basis and buttress of the state. Learning, hand in hand with wisdom; the power to do and the wisdom to create; scientific attainments and talent for their fruitful employment; appreciation of art and literary culture—the university in fact, lies, one and all, within every real education."*

The complete education must always include at least five departments, each fully developed as may be possible in the

* "The New Education and the New Civilization."

period to which reference is had—viz.: physical, intellectual, moral, æsthetic, and religious. These several divisions being wisely supplied, the health of the student is insured; his intelligence is enlarged and broadened; his relations to his fellows and to the spiritual world are made acceptable; his tastes are made capable of giving him and his associates pleasure; his soul is assured of content. Each form involves the giving of two desirable gifts: discipline of the faculties thus cultivated, and knowledge of the subject to which they are related. A general education supplies largely the first; the technical education gives mainly the second: the discipline being incidental in the latter, the knowledge incidental in the former case. The education of a nation must be so directed and provided for that it shall offer the citizen the means of securing culture and the means of gaining a livelihood. The last is essential to the life of the individual and of the nation alike; the former makes life desirable to the citizen, and the nation helpful to the world. It is in the completion of the scheme of education by the more satisfactory and general introduction of the essential element of education that modern advances in this field are distinguished; and the contemporary technical school is the latest and highest step in this path.

The "incomparable philosopher, Sir Francis Bacon," as George Herbert calls him, in his fifth chapter of his "Advancement of Learning," first division, discusses "The Partition of the Operative Knowledge of Nature into Mechanick and Magick." Modern science has merged the Magick into Mechanick in such effective manner as has brought all the then mysterious powers of earth, air, sea, and the outer universe into service in the performance of wonders in view of which Aladdin's marvels shrink into insignificance; and her votaries may, with more justice than Bacon, claim, "And of Magick, thus much: the name whereof we have vindicated from reproach and separated the true and noble kind from the base and counterfeit."

Progress in the United States, although so early begun, in this direction, has gone neither as far nor as thoroughly into the newer fields as every citizen would wish; but it has nevertheless been, of late, very considerable, and its movement is to-day an accelerating one, promising, in the near future, to become as rapid as is desirable or as is likely to prove wholesome. The movement in favor of a national university which would be what President Schurman would call "A People's University" was perhaps

the first though an as yet unfruitful one in the direction of the organization of the system now gradually taking form as the new illustration of Milton's "perfect education." The ideal form of this "cap-sheaf" of the educational pyramid is sufficiently well indicated by the writers from whom I have quoted; but perhaps most perfectly by President Schurman, thus:

"A people's university, if it is true to the spirit of the age, must hold all subjects equally reputable, and provide instruction in all alike. Least of all can it afford to omit those industrial arts which lie at the foundation of our modern life. But, with them, it must include every interest of the people which admits of scientific treatment. The masses and the classes must both be represented. Or, rather, such a university can recognize no such distinction; for the objects of every occupation must be esteemed equally significant. The analysis of soils is as important as the analysis of literature. The steam-engine is as sacred as Greek. Philosophy is not more venerable than road-making. A house is as rational as the geometry that it embodies. We must no longer dream that the little section of knowledge that we cultivate is the holy of holies. Every atom of the universe is equally worthy of regard.

> "'All are but parts of one stupendous whole,
> Whose body nature is, and God the soul.'

". . . In God's universe there is nothing common or unclean, and whatever is known about it must have a place in the curriculum of a people's university."

As the same able writer and eloquent speaker has asserted, the curriculum must be as varied as are the wants of the people. The day of the people has arrived, and "if, since the foundation of Salerno, universities have been dedicated to the investigation of nature with a view to providing a remedy for human diseases, they now assuredly need a fuller consecration to the same service for the additional purpose of rendering more available to our helpless race those natural powers and operations by which the works of man are affected and the life of man sustained."

We have now to trace the development of this modern movement in the direction of universal education and the curriculum of a "people's university," and toward a curriculum for the whole educational system into which the public schools, the special schools, and that university are, in time, necessarily to be built. This movement, so far as peculiarly modern, consists in the intro-

duction of the manual training schools, the trade schools, and the schools of engineering, either independently or as a part of existing systems and already established institutions. We are here mainly concerned with the schools of engineering, including, as they commonly do, various other departments of technical instruction.

THE LITERATURE OF THE SUBJECT is not very extensive. Mr. John Scott Russell's classical work on "Technical Education" is still, though a generation old, probably the best general discussion of the reasons for and the importance of the new phases of education. The regular reports and the special discussions relating to the history and the operation of the technical schools of the United States, issuing from the *Bureau of Education* at Washington, contain a large amount of exceedingly valuable and interesting matter. Until recently, these reports gave us nearly all that was known of the later progress of this great movement in this country; but during the past year a series of articles in the *Engineering News*, commencing on March 19, 1892, has given the most complete and authentic discussion of the contemporary state of this movement that has yet appeared. In the present paper, these sources of information, and such others as have been found available, will be drawn upon freely, with due credit to the writers who have thus aided in making the task here attempted a comparatively easy one. The writer has also gone over this field, at an earlier date, in collating matter for the report of the New Jersey State Commission, already quoted, and the facts then ascertained are here republished, so far as suitable to our purpose.

The State boards of education, in some cases, supply excellent material and valuable statistics, particularly; and special papers in the current periodical literature often supply otherwise unobtainable information. Historical accounts of the larger colleges and universities, and often of smaller institutions, are often issued under the supervision or with the recognition of the subjects of their text, and these will be found especially valuable when seeking information. The "Circulars of Information of the Bureau of Education," particularly the "Contributions to American Educational History," edited by Prof. Herbert B. Adams, and among them, that which contains the "History of Federal and State Aid to Higher Education in the United States," by Professor Blackmar, are most satisfactorily workable mines of this kind of knowledge. A special "Report on Industrial Education in the United States" was published by the same

bureau in 1883, which contains a large amount of matter relating particularly to the operation of the land-grant legislation.*

THE HISTORY OF THIS DEPARTMENT OF EDUCATION, as already indicated, dates back to the days of the Ptolemaic university at Alexandria, and, in fact, no real "People's University" has appeared since.

A system of education having for its object the preparation of artisans and laboring men to do their life's work with intelligence, skill, and economy, rendering all available knowledge subservient to the successful prosecution of their work, is not of recent origin. It was proposed by the most learned men of earlier times, long before any actual step was taken looking toward its introduction.

Despite the non-utilitarian ideas of so many among the early Greek philosophers, the great Alexandrian Museum, founded three centuries before Christ, was made, so far as it was possible in those early days, a technical school, and the principles of science there taught were, for centuries, of direct value in the encouragement of the growth of all the then known industries.

Ptolemy and other astronomers taught seamen the motions of those stars upon which they relied for guidance. Archimedes and other engineers of that time were, at the same time, philosophers and mathematicians; and every art, whether of war or of peace, had its representative practitioners among the attendants at that great seat of learning.

The Roman and Saracen universities and schools, of still later times, were not wholly "gymnastic" and non-utilitarian in character, and the arts often received new developments, and were frequently given a new impetus, by those discoveries of the philosophers and schoolmen which were promulgated by the investigators themselves, or by their disciples.

The earliest proposal to create a system of education, and a school especially adapted to the development of sciences as applied to the arts and to the instruction of persons engaged in those various branches of industries which have direct dependence upon science, or in which science is directly applied, was probably made by the Marquis of Worcester, two centuries or more ago, and by Descartes and contemporary French savans.

* A catalogue of the publications of this bureau, with a subject index, was issued from the Government Printing Office in 1891. It consists of about one hundred pages, 8vo.

Nothing was done in Great Britain until long after the system had been inaugurated and had been given form on the continent of Europe.

In this great social and peaceful revolution France took the lead, but only many years after her great philosopher had urged its inauguration. Descartes proposed the erection of a large lecture hall for each trade, which should be supplied with cabinets of apparatus illustrating the principles of science finding application in that branch of industry, and with collections of all the machines and the tools which were customarily used in the trade. Each of these lecture halls was to be placed in charge of a professor thoroughly familiar with the principles of science and practically acquainted with the methods of work and the mechanism with which the artisan was to be made familiar; and, under his direction, a systematic course of tuition was to be pursued, having for its object the instruction of the artisan in all those branches of science which were likely to prove useful to him, and in all those details of manufacture and of manipulation which he ordinarily learns, painfully and slowly, only by unguided experiments and observation. In art, as in science, systematic instruction only can make the practitioner thoroughly expert and give him a maximum amount of useful knowledge with the least expenditure of time and of mental and physical energy. It was only in the century succeeding Descartes that an actual beginning was made. For this, the most important step ever taken by any modern nation, France is indebted to the celebrated engineer and mechanician, Vaucanson. Throughout his life, this great man was constantly collecting curious, useful, and ingenious mechanisms, and was unceasingly inventing and constructing devices even more ingenious and intricate than any he obtained from others. Before 1775 Vaucanson had gathered together at l'Hôtel de Mortagne the earliest collection of mechanism and of philosophical apparatus that was ever used to endow a purely technical school. The collections were bequeathed by Vaucanson to the state, and it thus became the germ of the *Conservatoire Impérial des Arts et Métiers.*

The people of France are probably the most comfortable and happy nation on the globe, a result which is to be attributed to their frugality and industry, and to the extent to which they have learned to incorporate taste and skill in each branch of industry—sustaining on an area about equal to that of the State

of Texas a population nearly equal to that of the whole United States; affording us the best evidence of the value of such statecraft as has been above described, and of the importance—not to say the vital necessity—of the immediate adoption of a similar system by ourselves.*

Germany was the earliest, probably, of all modern nations to recognize the necessity of establishing a complete system of education under the supervision of state officers, and comprehending all portions of the country and all classes of people. Germany was the first European nation in which education became a recognized science, and a science which is second in importance to no one of those to which it has given birth, and the growth of every one of which is so entirely due to its beneficent influence. The first efforts to establish a school system under the direction of a government, state or municipal, and for the advantage of the whole people, were made a thousand years ago and more, and, after the introduction of the art of printing, over four centuries ago, the progress of popular education became rapid and was never interrupted.

Martin Luther was one of the earliest apostles in this most thoroughly "missionary" of all known kinds of labor for the public weal; and the names of Trotzendorf, Sturm, Neander, and Comenius are among those which should never be forgotten as pioneers in this noble work; they lived during the sixteenth and seventeenth centuries. They had worthy successors in Spencer and Francké immediately after the introduction, subsequent to the Thirty Years' War, of the system of compulsory attendance at schools. The former devised and introduced the modern catechetic method of instruction, while the latter, his pupil, founded, in 1696, the celebrated orphan asylum and school at Halle. These great men were succeeded by Basedort and by Pestalozzi.

The complete reorganization, in 1809, of the German school system led to the formal recognition of the fact, now everywhere acknowledged and acted upon, that the government of every state is bound to the community, "as a matter of right, duty, and interest," to establish the best and most extended practicable system of education in all branches which are of direct and immediate applicable value to the mass of the people, and to secure the opportunity to the well-disposed and to compel the ill-disposed to take advantage of the privileges thus provided.

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* New Jersey Report.

As early, at least, as 1757 we find a beginning to have been made in the direction of technical instruction. At that date Councillor Hecker founded the "Real Schule" of Berlin; in which, at a time when the Greek and Latin languages and literature were the only subjects taught in the schools, generally, it was the declared intention to teach "not words simply, but realities which should be explained from nature, and from models and plans, and which should comprehend subjects which would be useful in after life."

A change, made by Hecker in 1769, divided the school into three: a classical school, a school of arts, and the German department.

It was only after the commencement of the nineteenth century, however, that trade schools were inaugurated. To-day, the German system of education includes an even more complete system of technical education, and a more general distribution of trade-schools, than is to be found even in France.

Said that distinguished British engineer and technicist, John Scott Russell, writing in 1869: *

"Twenty years ago, professional duty took me to Germany for the first time. I cannot forget my first impression at the sight of whole nations growing up in the full enjoyment of systematic, organized, I might almost say perfect, education. I had already become acquainted with some theories and forms of education. I had read Plato's description of the perfect training for a nation. I was familiar with education in England, in Scotland, and in France. I was familiar with elementary school teaching, and enjoyed the privileges of university education and the still higher education of the workshop. I was familiar with the systems of Bell and Lancester, having had personal acquaintance with its authors, and had myself taken an active part in schools of art and mechanics' institutions; but I confess to have been profoundly astonished—I may say humiliated—at the sight of nations whose rulers had chosen to undertake the systematic education of their people, and of peoples who had chosen to bear the burdens and to make the sacrifices necessary to obtain it. I do not know to what men or class of men in Germany the forethought, organization, and patriotism are to be attributed which made them lay aside personal ambition, political animosity, religious sectarianism, and state parsimony, in order to unite all classes of the people in

* "Systematical Technical Education." London, 1869.

a unanimous effort to raise every rank in society to a higher condition of personal excellence and usefulness, and, by diffusing equality of education, to extinguish the most grievous of class distinctions."

The German system of technical and of trade education is thoroughly complete and as thoroughly national. Every German state has its preparatory schools, its trade schools, its polytechnic schools; and some have even the technical university. It is sufficiently evident, that, in Germany even more than in France, the governing and the educated classes, instead of standing aloof from each other, and instead of forgetting, as is too generally the case in our own country, those great facts and those imperative duties which every statesman does, and which every citizen should, recognize, have worked together for the common good, and have given Germany a vantage ground, in the universal struggle for existence and wealth, which is likely, in the future, to enable that country for many years steadily to gain upon all competitors. Recognizing these facts, and the necessity of promoting in all possible ways the efficiency of the industrial system, every modern legislature has sought to advance in all practicable ways the effectiveness of technical education.

J. Scott Russell, referring to technical education in England, says: "The English live in the midst of an energetic rivalry of competing nations. The aim of our national life should be to do the work of the world better, more ably, more honestly, more skilfully, and less wastefully than the skilled men of other countries. If we are less skilled and less honest than others, we are beaten in the race of life. To the national welfare and success, it is therefore necessary that the young race of men who are to do the work of England, . . . shall, each in his own special profession, occupation, trade, or calling, know more thoroughly the fundamental principles, wield more adroitly its special weapons, be able to apply more skilfully its refined artifices, and to achieve more quickly, perfectly, and economically the aim of his life, whether it be commerce, manufactures, public works, agriculture, navigation, or architecture. . . . What I call technical education is that kind of training which will make the new generation of Englishmen excel the new generation of foreigners in this coming rivalry of race and nation."

The same remarks are equally true as applied to the United States; for the Atlantic Ocean has ceased to be, to any important

extent, a wall of defence against foreign competition in the refined industries, in those which bring wealth to the worker and diversification of industries to the nation. Our school and college curricula have hitherto been—and are still in fact—vastly too exclusively literary to meet the needs of the people and of the country. We have made hardly a beginning in the upbuilding of that great system of industrial training supplementing education which must, if we are to survive in the industrial rivalry of nations, soon be made to constitute an important and extensive division of the state and of the national educational structure.

In his report on technical education in the United States, Mr. Wm. Mather, of Manchester, England, remarks:

"The effect of the public schools, colleges, and universities, supported by taxation of the people, is more marked in general education in literary branches, and in this direction their influence is not altogether a benefit. Too large a class of young people in America of both sexes are seeking pursuits not requiring manual labor. Their education, as given at present in the high schools and colleges"—he might have included the lower schools—"tends rather to unfit them for the active industries of life, in a country where the vast resources of nature are waiting for willing and trained hands to utilize them. The native-born American hates drudgery; and all the mechanical arts, when pursued without some knowledge of science to employ and interest the mind, are more or less drudgery. The American boy, with his inborn ambition and natural ingenuity, would cease to regard manual labor as drudgery if his hand and mind together were industrially trained through the school period. He would then be led into industrial employments by choice, as the readiest means to climb to a higher position in life. All Americans have more or less of the mechanical faculty. It is the characteristic of the race. The problems involved in settling the country have been more mechanical than political. In early times almost all men and all women were engaged in manual work and in exercising their wits to avail themselves of the forces of nature. To this natural bias the public-school education gave the means for higher development. The demand for mechanical contrivances to save labor held out the promise of great reward; and the protection of cheap patents gave confidence and security. Thus the workingmen of America have been educated and brought up under conditions different from those prevailing in Europe."

These remarks are less true to-day than they were when written some years ago, but it still remains the fact that our educational methods and our schools are largely constituted on the older models of the cloisteral period, and are not even approximately what the intelligent patriot and the wise statesman would desire to see them. And this is true, also, in spite of the indubitable fact that our people excel in many arts. They would excel still more, and more generally, were ours a technically trained nation.

The Centennial Exhibition did more to impress the world with the resources and possibilities of the American continent and people than was either anticipated or realized. It awakened anew an interest in what we manufacture and invent. Those who visited our shores from abroad allowed some of their impressions of what they saw at the Exhibition, and elsewhere, to come back to us through channels of high authority and significance. For instance, the correspondent of the London *Times* said: "The competition at Philadelphia has not altogether satisfied us. It is true that every nation has the advantage in exhibitions held within its own area; but the products of the industry of the United States surpassed our own oftener than can be explained by that circumstance. It appears as if there was a greater economy of labor habitually practised in the United States. . . . In comparing results with our own, we are painfully suspicious that they reveal the application of more brains than we always have at our command."

With our people well-educated and well-trained in the refinements of every art, how much more ought they with their active and ambitious minds, their skilled and always-ready fingers, and their extraordinary ingenuity and constructive ability and perfect freedom of movement and thought, to excel all other nations in effectiveness in the accumulation of every product of human ingenuity and skill! Seventeen years have gone by since that time, and we have now in the Columbian Exhibition at Chicago the concrete results, shown by sample, of the education, the training, and the accumulated experience and practice of a half-generation since the Exhibition of 1876. Technical education, manual-training and trade schools, unfortunately, have been as yet unable to do much to promote the nevertheless vast progress thus illustrated; but we may at least hope that we shall not be found far behind in the industrial race. Given another generation of opportunity with such aid as systematic and skilful

training can offer our people, and we may fairly hope to see ourselves safe from more than stimulative and healthy competition.

Mons. Dwelshauvers-Déry sends me his report to the Belgian government upon the steam engines exhibited at Paris in 1889, in which, referring to the number and brilliancy of American inventions and the extent to which Europe is indebted to this singular and characteristic feature of the mental organization of the American people, he says :

" The question may well be put : Whence comes this exuberance of activity on the one side of the Atlantic, this listlessness on the other ? How happens it that the master-thought is sent across an ocean to Europeans, who are reduced to the *rôle* of manufacturers only ? Perhaps the answer would be the more readily found if we were to leave the domain of mechanics and look from the higher point of view at the social conditions of the two continents. . . . Does not the difference come of the education of these peoples ? In the United States it is free everywhere ; everywhere creative and expansive as liberty itself. In Europe it is regulated, powerfully organized, the work of a despotism, coming from the barracks. Its aim seems to be to reduce to uniformity all the members of the social body, to cast them all in one mould, to make them, as it were, interchangeable. It is forgotten that the trees of a forest can be brought to equal height only by cutting down the higher ones to the level of the lower ; that the education of organisms is not effected by the hammer, at the anvil, in the mould, or by a process of milling. The first of its duties is to respect individuality while at the same time developing it fully. . . . Let us have less, much less, dogmatism in teaching. Let the youth be trained in the laboratories, as is already the case in England and America. Let the schools and laboratories be opened widely, leaving the young people ready, free to consult their natural aptitudes without submitting them to a succession of examinations by which their knowledge is appraised to the hundredth of one per cent., and without dropping them out of the school because they have failed in a branch the study of which is repulsive to them, and which they will probably never in their whole lives make use of. . . . Public prosperity exacts a reform which is based upon respect for individual freedom. . . . The true democratic principle is to give to each one the place which his personality merits, and an atmosphere about him suited to his development : ' the right man in the right place.' "

FOREIGN SCHOOLS, as already stated, began their work with the institution of the French "*Conservatoire*," with the equipment given it by Vaucanson, and the "*Conservatoire Impérial des Arts et Métiers*," as it is officially called, was placed under the directorship of M. de Vandermonde, who increased the collections by the addition of about five hundred machines between the years 1785 and 1792. The establishment was, a year later, 1793, placed in the hands of a "*Commission temporaire des Arts*," and, still later, the present title was conferred upon it by a degree of the *Convention Nationale*. The *Commission temporaire* were fortunately able to preserve these splendid collections uninjured during the disturbed period of revolution in which they had charge of them, and even procured from the Convention a decree making their charge a *dépot public* and authorizing the appointment of three "*demonstrateurs*" and a designer to conduct a course of instruction. A little later, the whole establishment was domiciled in the old priory of *Saint-Martin-des-Champs*, and its subsequent history has been marked by a success of which the French people may well be proud. Among its faculty lists have been, and are still, numbered many of the greatest names known to France and the world. Thenard, Charles, Darcet, Dupin, Clement, Berthollet, Gay Lussac, Arago, Pouillet, Poncelet, Ollivier, Bequerel, Moll, Alcorn, Tresca, and Morin are names familiar throughout the civilized world.*

The *Conservatoire* was not actually constituted a school of technical instruction, however, until 1819, and it has never been a school for the workingmen of France, but has been devoted to the education of students for the higher positions in the industrial system and to the training of professional engineers.

A more typical example of the form of industrial school which is most effective in the development of manufactures and the arts is the later "*École Centrale des Arts et Manufactures*," founded at Paris in 1829. This school was taken in charge by the government in 1858, and has since that time formed a part of that general system of industrial education to which France so largely owes her present position as a wealthy and prosperous nation. Students from all parts of France, and from other countries as well, are admitted. Although large numbers of the students are foreigners, this institution remains, as it was said by Mr. Morin and M.

* R. H. T. in New Jersey Report, p. 28.

Tresca, "*pour l'industrie, une des forces principales*" of France.* Founded originally by an association of scientific men, which included MM. Dumas, Peclet, Ollivier, and others hardly less distinguished, it stood unaided nearly thirty years and finally became one of the pillars of the state, and to-day furnishes a large proportion of the civil engineers of France. †

Other schools—as the *École Polytechnique*, *l'École des Ponts et Chaussées*, at Paris, *l'École des Miners*, at St. Etienne, and that at Alais, *l'École des Arts et Métiers*, at Chalons, those at Aix and elsewhere, and the *Écoles Industrielles* at Mulhouse, Lyons, Lille, and in other cities—aid in making the system of industrial education of France admirably perfect. These schools, with the exception of the *Ecoles Industrielles*, are under the direction of the state.

The trade schools are usually founded by municipal authority and are under the direction of the city governments creating them. They fit young men to become good workmen and excellent superintendents. They are devoted peculiarly to instruction in the practical operations which constitute the trades. The *Polytechnique*, which is, in a certain sense, the highest of the French technical schools, is largely, perhaps principally, a school of mathematics and of the pure allied sciences. *L'École Centrale* is the highest of the properly so-called industrial schools, and educates leading manufacturers and the directors of great industrial establishments. Its graduates hold the highest positions in France, and the principal railways, the most extensive mines and metallurgical establishments, and the great manufactories of textiles, of paper, of glass, of machinery, and even of chemicals, are usually directed by graduates of this admirable school.

The trade schools of Chalons, Aix, and Angers were organized by a decree of December 30, 1865, for the instruction of all workers in wood and iron, and are only allowed to receive resident pupils, who are selected from among applicants for admission by a competitive examination, at the age of fifteen to eighteen years. The graduates are usually found to have acquired some dexterity in the use of tools, are generally good draughtsmen, are well grounded in the principles of mechanics and of the

* "*De l'Organisation de l'Enseignement industriel et de l'Enseignement professionel.*"

† Letter from Gen. Morin to Mr. Jas. Forrest, Secretary of the British Institution of Civil Engineers.

arts to which their attention has been devoted. These schools graduate three hundred or five hundred young men annually, who find employment in the large manufacturing establishments as foremen and managers, after passing through a period of service as draughtsmen or workmen. They frequently ultimately become employers.

In some of the other, and especially the mining schools, etc., instruction is free, and the pupils are admitted after successfully passing a competitive examination. Naval and military schools are instituted and administered under the direction of the bureaux of the navy and the army, and supply both officers and privates with technical instruction appropriate to their wants; and the government supports, also, schools of agriculture and of forestry.

The French weaving schools are usually conducted in connection with a large technical school, or with an "Industrial Association"—a society which is somewhat peculiar in its character and objects, and which has no representative in the United States.

These societies are composed of merchants, manufacturers, and tradesmen—usually without restriction as to membership—and the expenses are defrayed by the collection of small annual dues, by the income which is sometimes derived from the publication of a periodical in which are printed papers written by members, and by small endowments which are often received from the government, when it has been shown that they are of real service to the country.

There have long existed in France, as in the other European countries, museums of art and art collections of many kinds, which are most effective means of instruction for the people of every class and of every position in society. There have also been established, in late years, special schools of art, as, for example, *l'École des Beaux Arts* and others, both day schools and night schools, which are frequently, probably usually, partly if not wholly sustained by the government. These schools are principally, as a matter of course, drawing schools, and the art of design and industrial as well as free-hand drawing is also becoming a more and more prominent study in the academies as well as in the technical and trade schools. In France, as elsewhere throughout the civilized world, these studies are becoming rapidly geometric in their character, and pupils are taught from the object instead of from the printed "study" which, in earlier years, was exclusively adopted.

Still another extremely important aid in the awakening and cultivation of that elegant taste and artistic skill for which France is famous, is the establishment of national manufactories of art products. The manufactory of Sevres ware is an illustration.

The finest of imported wares are constantly procured and studied; all new or peculiar methods of manufacture are investigated; every known expedient for obtaining excellence of material and superiority of finish is tested, and the best talent of the country is drawn upon in the effort to make the establishment preëminent not only as a manufactory of artistic products but as a school for French taste.

The result of this systematic and directly practical education of the French people, and of the enlightened policy which has thus developed every industry of the country and which has, by patient and skilful training, made available, to the highest possible degree, the inherent taste and artistic instinct of the French people, during two or three generations, is plainly seen in the present condition of French industry, and especially in those branches of art industry in which that country has held the leading position during so many years.*

The system is very nearly the same in all German states, and is sustained partly by the general government, partly by the several municipalities in which the schools and colleges are situated, and partly, as in France, by industrial "unions," like that already described—the *Union Centrale*, of Paris. The schools of the latter, in Germany, however, must be licensed by the state. These latter are trade schools, founded with the object of benefiting certain branches of industry; thus there are weaving schools, schools of design, schools of mechanism, of bleaching and dyeing, of photography, of house and ship building, and schools for women in which sewing, cooking, and other kinds of women's work are taught.

Of the three grades there are probably six hundred schools in Prussia alone, of which one-half or more are of the primary grade, and some two hundred and fifty of the middle grade, and three of the highest type of technical college.

Tuition is given to workmen and artisans and their children, to engineers, teachers, proprietors of establishments and other

* Letter from Gen. Morin to Mr. Jas. Forrest, Secretary of the British Institution of Civil Engineers.

citizens in both day schools and night schools and often on Sunday.

These schools are usually permanently established and are in operation at all seasons. Some, however, are only kept open in winter.

The highest class of technical schools in northern Europe comprise institutions like the *Gewerbe Academie* of Berlin, the Polytechnic School at Hanover, the *Gewerbe Institut* of Aix-la-Chapelle, the Polytechnic School at Dresden, that at Brunswick, and, in the southern districts, the schools of Munich, Vienna, Carlsruhe, and Zurich.

The other German states are similarly well provided with educational institutions, teaching their people all the scientific and technical knowledge demanded in the intelligent and successful prosecution of the various branches of industry in which the highest skill and greatest knowledge is most fully awarded by an ample pecuniary compensation.

The best known, perhaps, of German trade schools is the "*Gewerbe Academie*" of Berlin. Students are admitted between the ages of seventeen and twenty-seven, if provided with certificates of competency from the "*Real Schule*" or from a "*Gymnasium.*" Foreign students are admitted if the school is not overcrowded with natives.

The school comprises a general technical department and a special technical school, which latter includes a school of mechanics, a school of chemistry and metallurgy, and a school of naval architecture. The second department is open only to students who have passed through the first; and those proposing to engage in constructive pursuits must have had some experience in the workshops, etc., before admission. They are also allowed to work at their trades or professions after entering the school and while attending lectures. Students working in the academy provide their own materials, and pay from one to two thalers per term for a lesson per week. Free scholarships are provided by the government to be assigned to meritorious students.

This magnificent "trade school" is more properly a technical university, and is deserving of especial notice, not only because of its great magnitude, but because of the thoroughness of its system and of its courses of study, the completeness of its illustrative collections, and especially the high character of the *personnel* of the institution.

Throughout Germany, technical schools and colleges, and trade schools are distributed so numerously that the visitor from the United States is not only impressed by the completeness of the system and by its universality, but is oppressed by the apprehension that his own country, unprovided with such efficient and essential means of giving to the people a good industrial education, and apparently having few citizens who understand the bearing of that fact upon the future prospects of the nation as well as upon the character and attainments and upon the happiness and prosperity of the people, is likely to suffer severely when, in the near future, direct competition with this educated and trained nation of artisans shall produce those sad consequences which history has over and over again warned us against.*

Long after their northern neighbors had inaugurated the new systems and methods of education, the Swiss commenced on a similar plan, and established a noble school at Zurich, where they placed some of the greatest instructors in Europe, and opened their "Polytechnicum" to students from all parts of the world; more than one-half the pupils are from other countries. The faculty consists of about a hundred professors, assistants, and private teachers, and the number of students is about one thousand. Courses are laid out for students which they are at liberty to follow or not, as they may choose. These courses occupy three years each. A preparatory course is also provided for students who are found unprepared to enter upon these regular courses. There are given, in all, about one hundred and fifty courses of instruction, which are divided into groups in such a manner as to meet the needs of special classes of students.

This technical university has an astronomical observatory with appropriate collections, a large chemical laboratory, an enormous physical laboratory, collections of models of engineering constructions, and a museum of earlier and of curious structures.

The institution also possesses laboratories which are devoted to research and special investigation.

The architectural museum, the collections in the department of natural history, and other collections are extensive, and all are rapidly growing.

This great college is supported by a population of about three millions of people.

* Letter from Gen. Morin to Mr. Jas. Forrest, Secretary of the British Institution of Civil Engineers.

It is unnecessary to devote further space to the continental schools. Sweden and Norway, Russia and Austria—all European nations, in fact—have the same system in a state of greater or less development, and are making of their people all that such education and training of the material available can. All are, in this matter, far in advance of our own country, which is becoming, as appearances would now indicate, comparatively an illiterate and uneducated nation in every department related to our industries.

Thus, as has been shown, a complete system of technical science instruction and of industrial education has been incorporated into the continental educational structure, which places before every child in the land the opportunity of giving such time, as the social position and pecuniary circumstances of its parents enable them to allow it, to devote to the study of just those branches which are to it of most vital importance, and to acquire a systematic knowledge of the pursuit which surrounding conditions or its own predilections may lead it to follow through life, and to attain as thorough a knowledge and as high a degree of skill as that time, most efficiently disposed, can possibly be made to give him. There is here no waste of the few months or years of, to him, most precious time which the son or the daughter of the humblest artisan can spare for the acquisition of a limited education. Every moment is made to yield the most that can be made by its disposition in the most thoughtfully devised way that the most accomplished artisans and the most learned scholars, mutually advising each other, can suggest.

One day in such schools as those here described is of more value to the youthful worker than a week in the older schools, or than a month in the workshop or the mill. Thus, while the fact is recognized that a general and a liberal education is desirable for every citizen, the no less undeniable fact is also recognized that few citizens can give the time to or afford the expense of a symmetrical general course, and that the interests of the individual and of the state unite in dictating the provision of such systems and means of industrial education and training as are now actually provided.

In Great Britain, although the government and the people of that country have initiated trade schools and technical and industrial instruction in a few cities, and in connection with such institutions as King's College, the University, and the Crystal Palace Schools, in London; Owen's College, Manchester; Trinity College,

Dublin; Queen's College, Cork, and with Glasgow and Edinburgh Universities, no such system of education and no such school system exists as has been so long in operation on the continent. So great is this deficiency, in fact, that a British engineer once advised all aspirants to the profession of civil engineering to go to Paris and take the course of study prescribed at *l'École Centrale*,* or to attend lectures at a German or a Swiss polytechnic school.

A large number of primary trade schools and polytechnic schools have been founded in the manufacturing cities of Great Britain, which are doing good work, and industrial instruction is, to a certain extent, given in other schools. The growth of the movement in that country is well indicated by the facts that, in 1860, there were but nine of these schools in cities like Bristol, Birmingham, and Worcester, while in 1865 there were 120, and in 1870 there were 799, the growth at that time (1865–1870) being at the rate of about fifty per cent. per annum. In establishing these lower schools the progress has been wonderfully rapid, and the results have been commensurate with the energy displayed in their attainment.†

But it is in the one department of industrial art education that the British nation has most wonderfully exhibited the energy and the thoroughness with which it usually carries on whatever work it may undertake in real earnest. As early as 1837 the government opened a school of design in Somerset House, London. Local art schools were opened in the manufacturing cities in 1841, in which year they had over two thousand pupils. It was not, however, until ten years later, when the International Exhibition of 1851 had fully revealed to the educators and the statesmen of Great Britain the immense superiority of the nations of the continent in all departments of art industry, that a beginning was made in so earnest a manner as to insure a real success, and it required another reminder in the great exhibitions of 1855 and of 1862 to stimulate that nation to put forth efforts which have resulted in the establishment of British art industries upon a basis which is as creditable as it is satisfactory. The work which has been accomplished is simply wonderful. From a position far, very far behind the continental nations, Great Britain has, in this one technical department, brought herself up into the very foremost place. This has

* C. Graham Smith, Opening Address before the Edinburgh and Leith Engineers' Society, November, 1875.

† *Ibidem.*

been done by means of large appropriations from the national treasury, not simply to support the schools of art, but also to defray the expense of prizes and of other special methods of promoting their efficiency and of securing the proper spirit on the part of pupils as well as of teachers. This national support is granted to the lower grades of common schools, to normal schools and classes for teachers, to night schools, and to special schools of art.

The whole system is directed by the central "Science and Art Department" at London, and its efficiency is largely due to this centralization of directing power, placing the instruction of the whole body—perhaps 800,000 students and teachers—under a single system which has been the outgrowth of the experience and observation of a quarter of a century.

A "National Art Training School," established at the South Kensington Museum, prepares teachers for the schools of art throughout the kingdom. Students are admitted by selection at a competitive examination. The best students receive fellowships. Other students pay from five shillings per session to five pounds in the various day and night classes. The extensive and magnificently complete museum is open to the students, where properly qualified, without charge.

It is in consequence of these wonderful exertions in this special line of progress that the art industries of Great Britain have become what they now are, most successful in rivalry with France. The exhibits of Great Britain at the International Exhibition at Philadelphia in 1876, and at Paris in 1878 and 1889, were illustrative of this most remarkable development. In *repoussé* metal work, in the finer ceramics, in all that combined taste, skill, and art, the exhibits of Great Britain were unexcelled by even the finest of other European products of the art industries.

The national system of technical instruction in Great Britain, as now organized, includes a large number of evening schools, and, in the large cities, these, which are commonly largely drawing schools, give instruction to immense numbers of ambitious and industrious scholars, who are occupied throughout the day in their regular vocations, usually the mechanic arts. In Manchester, for example, Mr. Llewellen Smith, in 1892–3, reports 14,000 students attending the evening classes of that city, as organized in connection with the technical schools.

According to the statement of the British Royal Commissioners

studying the German schools some years ago, all the European schools in which engineers or artisans are trained may be reduced to the following groups:

I. Polytechnic or technical high schools, in which the principles and practice of engineering are taught, sometimes with the aid of a workshop, but generally without it. The graduates aspire to be managing engineers of mines, railroads, manufacturing establishments, etc., each according to his special preparation.

II. Intermediate technical schools, subdivided into (1) general technical schools, (2) weaving schools, (3) industrial art schools. The general technical schools may be classified into (*a*) higher elementary technical schools, (*b*) secondary technical schools, (*c*) building and mining schools. The graduates of these schools expect to become foremen in shops and works, with the possibility of attaining to a manager's position.

III. Apprenticeship schools for the training of skilled workmen.

IV. Evening schools, available for artisans. These are attended by men who during the day follow their craft. The Fortbildungsschulen, or continuation schools, belong in this category.

V. Trade and professional schools for women.

This classification may be still further simplified in relation to mechanical engineers, foremen, and artisans, and all schools devoted to their service will fall under one of the following heads: (1) polytechnic schools, with or without workshops; (2) secondary technical schools; (3) apprenticeship schools; (4) trade schools.

For admission, the polytechnics require sometimes more than the equivalent of an American college course, as the *École Polytechnique;* sometimes the equivalent of a full course at the Realschule, as at the German polytechnics; sometimes, the best that the preparatory schools cangive, as at the Imperial Institute of Technology at St. Petersburg. The range and severity of the requirements for admission gradually diminish till in the apprenticeship schools only the rudiments of knowledge are demanded.*

The "*Gymnasia*" in Germany are preparatory schools for the "*Polytechnicum*" as well as for the universities; but the special preparatory schools for the former are usually the "*Realschule*": although many learned men and some members of the technical

* Bureau of Education, Circular No. 3, 1885. Notes by Dr. C. O. Thompson.

professions, as the late Dr. Hofmann, Dr. Meyer, of Zurich, and others, prefer the gymnasia. In the United States, the question has become practically settled by the fact that the freedom of choice allowed the people has resulted in their giving up the classical training almost absolutely in their preparation for the technical colleges, and even in large measure as a part, or the main part, of a liberal training. They have confined themselves, even in preparation for general culture, to modern literatures and languages and the other customary studies, to the exclusion, very largely and often entirely, of the ancient languages and literatures.

In Europe, the custom has come to be almost universal to isolate the technical schools from the classical institutions and older universities. This has come about partly through the conviction that better work will be done by each class of college if allowed to work unhampered by the different methods and even the conflicting views, feelings, and traditions of the other; partly, perhaps, in consequence of their different foundations. Many able men favor both systems, and the amalgamation of the university and the technical school is likely to be given faithful trial here and there on the continent, and in Great Britain perhaps still more completely; but they are to-day practically separately administered in nearly all cases. The view of the relative importance of manual and of gymnastic training of the mind which prevails generally in Europe is that, in the higher schools of technology at least, the training of the hands constitutes no part of the essential education of the engineer even, and that these schools should confine themselves entirely to the instruction of the student in the principles of his art, avoiding the practice, so far as it involves the use of the hands. It is perhaps a consequence of this belief and practice that the states of Europe have been, for years past, flooded with well-educated, untrained young aspirants for entrance into this vocation who not only have been unable to find employment, but who have, in many instances, been informed by employers that they are not wanted. It is the man who suitably unites theoretical and practical knowledge and training, who is wanted and who best succeeds, in Germany no less than in the United States. The view held by so many of the higher schools of Germany and of France is that formerly inspiring the "*École Polytechnique*" at Paris, the first institution working on the highest theoretical plane produced in Europe. The French "*Conservatoire*

des Arts et Métiers," on the other hand, was the first to represent and promote the opposite system; but even this great institution of practical training is not a trade or manual-training school. That class is represented, in France, by the schools at Châlons and elsewhere.

Reporting upon the continental schools, the British Commissioners, after a careful and exhaustive examination of their methods of establishment and operation, say:

"With the exception of the *École Centrale* of Paris, all these schools have been created and are maintained almost entirely at the expense of the several states, the fees of the students being so low as to constitute only a very small proportion of the total income. The buildings are palatial, the laboratories and museums are costly and extensive, and the staff of professors, who are well paid according to the continental standard, is so numerous as to admit of the utmost subdivision of the subjects taught. In Germany, as we have stated in a previous part of our report, the attendance at some of the polytechnic schools has lately fallen off, chiefly because the supply of technically trained persons is in excess of the present demand; certainly not because it is held that the training of the school can be dispensed with. The numerous young Germans and Swiss who are glad to find employment in our own manufactories have almost without exception been educated in one or other of the continental polytechnic schools.

"Your commissioners cannot repeat too often that they have been impressed with the general intelligence and technical knowledge of the masters and managers of industrial establishments on the continent. They have found that these persons as a rule possess a sound knowledge of the sciences upon which their industry depends. They are familiar with every new scientific discovery of importance, and appreciate its applicability to their special industry. They adopt not only the inventions and improvements made in their own country, but also those of the world at large, thanks to their knowledge of foreign languages and of the conditions of manufacture prevalent elsewhere.

"The creation abroad of technical schools for boys intending to become foremen is of much more recent date than that of the polytechnic schools. To this statement the foundation during the First Empire of the three French *Écoles des Arts et Métiers*, at Châlons, Aix, and Angers, is only an apparent exception, because they simply vegetated until their reorganization within the last

twenty-five or thirty years. Mining schools were, however, established in Prussia in the last century and in France about 1817. Among the examples of schools for foremen are those of Winterthur in Switzerland, Chemnitz in Saxony, and Komotau in the Austrian dominions, principally for engineers; and the *École des Mines* at St. Étienne, the latter more especially for mining and metallurgy. The theoretical instruction in these schools is similar in character but inferior in degree to that of the great polytechnic schools. On the other hand, considerable attention is devoted in these schools to practical instruction in laboratories and workshops, which is not the case in the polytechnic schools. In Prussia, as will be seen from the ministerial report found in the appendix, a beginning has been made in the establishment of such secondary technical schools, but, in the words of the report, 'its execution will be tedious and costly.' In Bavaria the *Industrie-Schulen*, which are technical schools of a grade inferior to the polytechnic school, give both theoretical and practical instruction, the latter in some cases highly specialized, in preparation either for direct entrance on an industrial career or for further study in the polytechnic school. In France technical schools of a somewhat lower type are being established all over the country. The one at Rheims, previously described, is an excellent example of these schools. The boys from the Rheims school either enter the *École des Arts et Métiers* at Châlons or go into manufactories or into business, in each case with a fair knowledge of theory and manipulation, as mechanics or as chemists.

"It is important to bear in mind that the French schools of the type of that at Rheims, though virtually advanced schools, now rank as superior elementary schools, to which the pupils are consequently entitled to claim admission without the payment of any fees.

"Up to the present time, however, although a few foremen have received some theoretical instruction in schools of this kind, foreign foremen have not generally been technically instructed, but, as in England, are men who, by dint of steadiness, intelligence, and aptitude for command and organization, have raised themselves from the position of ordinary workmen.

"The continental weaving schools may, on the whole, so far as their influence on trade is concerned, be ranked in the first and second categories; that is to say, they are attended by those who propose to become merchants, manufacturers, managers, or fore-

men. They are held in the highest estimation by some of the most intelligent and successful continental manufacturers; of this there can be no better proof than the erection, in substitution for the one already existing, of the splendid new weaving schools at Crefeld, probably the most flourishing centre of the general silk trade, at the joint expense of the state, the locality, and the commercial body."

The British commissioners come to the following conclusions:

"In dealing with the question of technical instruction in this country we would, at the outset, state our opinion that it is not desirable that we should introduce the practice of foreign countries into England without considerable modification. As to the higher education, namely, that for those intended to become proprietors or managers of industrial works, we should not wish that every one of them should continue his theoretical studies till the age of twenty-two or twenty-three years in a polytechnic school, and so lose the advantage of practical instruction in our workshops (which are really the best technical schools in the world) during the years from eighteen or nineteen to twenty-one or twenty-two, when he is best able to profit by it.

. . . . . .

"In determining what is the best preparation for the industrial career of those who may expect to occupy the highest positions, it is necessary to differentiate between capitalists, who will take the general as distinguished from the technical direction of large establishments, and those at the head of small undertakings, or the persons more especially charged with the technical details of either. For the education of the former, ample time is available, and they have the choice between several of our modernized grammar schools, to be followed by attendance at the various colleges in which science teaching is made an essential feature, or the great public schools and universities; provided that, in these latter, science and modern languages should take a more prominent place. Either of these methods may furnish an appropriate education for those persons to whom such general cultivation as will prepare them to deal with questions of administration is of greater value than an intimate acquaintance with technical details. It is different in regard to the smaller manufacturers and to the practical managers of works. In their case, sound knowledge of scientific principles has to be combined with the practical training of the factory, and therefore the time which can be appropriated to

the former—that is, to theoretical instruction—will generally be more limited.

"How this combination is to be carried out will vary with the trade and with the circumstances of the individual. In those cases in which theoretical knowledge and scientific training are of preëminent importance, as in the case of the manufacturer of fine chemicals, or in that of the metallurgical chemist, or the electrical engineer, the higher technical education may with advantage be extended to the age of twenty-one or twenty-two. In the cases, however, of those who are to be, for example, managers of chemical works in which complex machinery is used, or managers of rolling mills, or mechanical engineers, where early and prolonged workshop experience is all-important, the theoretical training should be completed at not later than nineteen years of age, when the works must be entered and the scientific education carried further by private study or by such other means as do not interfere with the practical work of their callings. Many colleges of the class to which we have referred have already arranged their courses to meet these requirements, and some of them, as will appear from our reports of visits, have workshops for the purpose of familiarizing the students with the use of machine and hand tools.

. . . . . .

"With reference to the subject of drawing, we cannot too often call attention to the extraordinary efforts which are being made abroad for instruction in art, more especially as applied to industrial and decorative purposes, and to the important influence of this instruction in furnishing employment for artisans on the continent. Without depreciating what has been done in this direction by the schools and classes under the auspices of the Science and Art Department in this country, and while fully alive to the importance of the organization which tends to the diffusion of art instruction over a wide area, your commissioners cannot conceal from themselves the fact that their influence on industrial art in this country is far from being so great as that of similar schools abroad. This is due, no doubt, to some extent to the want of proper and sufficient preparation on the part of the students, owing to the inadequate instruction they have received in drawing in the elementary schools."

These remarks might be repeated with vastly more force in reference to the condition of art in the United States.

The administrative basis of the German system of education,

according to Matthew Arnold, lies in the *Allgemeine Landrecht* of Frederick the Great, and promulgated in 1794; which common law of Prussia includes these assertions and principles:

"Schools and universities are state institutions having for their object the instruction of youth in useful information and scientific knowledge. Such institutions are to be established only with the previous knowledge and consent of the state."

The Prussian constitution of 1850 also contains the following:

"All public and private establishments" (of education) "are under the supervision of authorities named by the state."

The drift of progress in the United States is obviously in this same direction; although it is not likely that, in this country, the state will ever assume to forbid the establishment of private schools independently of the government or to in any manner control them. It does, however, take upon itself more and more the duty of offering education of every grade to its own people. It is in every State approximating the condition which offers to every citizen and to all citizens' children that ladder which "rises from the gutter to the university." It is through this liberal and statesmanlike action of Germany and her neighbors that we find in some provinces as many as one student in the universities for every thousand inhabitants, and an average for the whole about 1 in 2,500 of the population, about twice as many as in England.

What foreign countries are doing in individual instances for the higher education may be understood from the statement of President Adams, that "one of the minor universities of Great Britain has recently completed a collegiate building at a cost of £500,000," and the Prussian Polytechnicum, at Charlottenburg, Berlin, represents four millions of dollars. The Zurich Polytechnic School has spent a quarter of a million of dollars on its chemical laboratory, and nearly as much in building its physical laboratory. "The little kingdom of Saxony, only half as large as Vermont, annually gives from its public treasury $400,000 to its university, although the institution itself has great wealth and the professors are supported mainly by fees from students." It is thus that European nations are carrying into effect a principle which was incorporated into the ordinance of 1787 by which the United States applied its great surplus to this purpose: "Religion, morality, and knowledge being necessary to good government and the happiness of mankind, schools and the means of education shall forever be encouraged."

American schools, so far as developed in the United States, have either been established, usually, by the several States or in compliance with an agreement entered into with the United States Government, under the terms of the Morrill Act of 1862, the "Land Grant Bill."

Three quarters of a century ago, the people of the United States entered upon one of those periods of renaissance in education which, at intervals of a few years, have marked the progress of educational work in this country, and "manual-labor" schools were established in many places, in which the college course of education was accompanied by a course of manual labor, either with or without compensation. A "Manual Labor Academy" was opened in 1829 at Philadelphia, which was said to be remarkably successful, the students employing their hours of rest from study in various kinds of bodily work. Every invalid resorting to this academy in the year 1830 was restored to health.*

A number of the States were provided with such schools by legislative action, and in several others private enterprise did what the State governments had not done in this way. Among others, the Stockbridge Academy, in New Jersey, introduced this change into its programme, and Gerrit Smith secured a similar arrangement for New York State at Peterboro.

A report to the House of Representatives of Pennsylvania, in 1832, indicated:

1. That the expense of education could thus be reduced one-half.

2. That three hours' work per day had an important beneficial effect upon the health and strength and in promoting good spirits among students.

3. That it had an equally useful effect upon the intellectual advancement of students.

4. That such a system is advantageous in that it aids the impecunious student to obtain advantages in education which are ordinarily only enjoyed by the rich.

5. That students thus trained make better citizens and more successful men than when not thus physically trained.

Many such schools were established, and the general result of this introduction of the system confirmed all that was asserted

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* *Race Education.* Sam'l Royce. New York, 1878.

of it by the committee just referred to. Some of these schools are still existing.

Such a system does not necessarily form a part of a system of technical education; but it is probably best that it should. It necessarily constitutes a part of every course of really effective trade education, and it is a part of the problem now presented to the educators of the people to determine precisely how this method of alternation of physical with intellectual labor can be made to yield maximum benefit by, at the same time, giving a needed amount of physical exercise and the most useful industrial training.

The interest felt by the people of the United States, and especially of the newer States, where everything depends upon the right start in this matter, in the education of their population, is illustrated by the fact that their State constitutions often contain formal and extended provision for providing and maintaining a system of education on the most liberal scale. Thus we have in the constitution of the State of California the following:

"ARTICLE IX.—EDUCATION.

"SECTION I.—A general diffusion of knowledge and intelligence being essential to the preservation of the rights and liberties of the people, the legislature shall encourage by all suitable means the promotion of intellectual, scientific, moral, and agricultural improvement."

The next section provides for the appointment of a State superintendent of public instruction at a salary equal to that of the secretary of state; and the third section provides similarly for county superintendents. All lands granted to the State by the United States, all estates of deceased persons leaving no heirs or bequests, are to be appropriated to the uses of the educational department. The constitution commands the establishment and maintenance of a public school system, with suitable arrangements for its support and proper operation in a satisfactory condition of efficiency. No public moneys are to be appropriated to sectarian schools, and no denominational doctrines shall be taught in the public schools. The State university "shall constitute a public trust," and is to be perpetually maintained, and is to be maintained also as a "Land Grant College," and held under the rule prescribed by the Morrill Bill of 1862.

The founders of the State and the writers of the constitution of California were obviously not at all inclined to disagree with

the assertion of Wendell Phillips: "Education is the only interest worthy the deep, controlling anxiety of the thoughtful man," and possibly had in mind the thesis of Confucius: "There being education there will be no distinction of classes." Their action, however, was only the continuance of the fundamental principle of a Massachusetts constitutional law, by which, in 1642, every hamlet of fifty householders was compelled to provide a school and a schoolmaster for the children of the village; for with the Puritans, as with the Scotch, "education was a passion," as Froude said of the latter. And while the old "humanities" are nowhere neglected in the provision of the State for the education of the people, it is everywhere recognized to be the fact that, for the people, "it is more important for the present generation to understand the uses of the various hand tools, how to build houses, and how to live in them, than to write better Greek than Homer, better Latin than Cicero, or recite the transactions of antiquity in a more charming style than Xenophon or Herodotus or Cæsar." "The characteristic of the 'New Education' is the attempt to train the faculties in their true order of development by those natural and divine methods whereby the infinite wisdom is schooling all men in the university of life."

"It is the glory of American universities, as it is of those of Scotland and Germany, to be freely accessible to all classes of the people." . . . "One praise which has often been given to the universities of Scotland may be given to those of America. While the German universities are popular but not free, while the English universities have been free but not popular, the American universities have been both free and popular." . . . "They are supplying exactly those things which European critics have found lacking hitherto, to America, and they are contributing to her political as well as to her contemplative life elements of inestimable worth." *

This observing and discriminating writer concludes: "As respects education, the profusion of superior as well as of elementary schools tends to raise the mass to a somewhat higher point than in Europe; while, the stimulus of life being keener, and the habit of reading more general, the number of persons one finds on the same general level of brightness, keenness, and superficially competent knowledge of common facts, whether in science,

* *American Commonwealth.* Bryce. II. 550.

history, geography, or literature, is extremely large. This general level tends to rise. But the level of exceptional attainment in that small but increasing class who have studied at the best native universities or in Europe, and who pursue learning and science either as a profession or as a source of pleasure, rises faster than does the general level of the multitude; so that in this regard, also, it appears that equality has diminished and will diminish further." *

"There is no finer vista of political progress in the development of the American Republic than that afforded by the changing views of education sustained by the people and constantly modified by marked political tendencies. There is no better example of the influence of politics upon culture and learning than that presented by a historical perspective of the ideas which have developed our great educational system." †

The early colonists sustained education and religious instruction as one and inseparable, and alike and inseparably entitled to public care; but they usually contributed to their support either through the churches or independently and privately. Colleges and universities as parts of a political system were not then thought of. But this idea came to the front immediately after the organization of an independent government, and the epoch directly following the Revolution saw some decidedly vigorous attempts to found institutions of higher learning in some of the States, and Pennsylvania founded her two State universities in 1776, and North Carolina her one institution in 1777. These universities were usually given very favorable and liberal charters, were usually exempted from taxation, often received special grants either in the form of endowment or of annual fixed appropriations, and, in the earlier days of the Republic, lotteries were not infrequently authorized for their benefit. Their officers and students were commonly exempt from duty with the State militia, and other special privileges were sometimes extended to them.

Harvard, Yale, Columbia, and other of the senior and now great colleges were thus aided by grants of land and money and special taxes, one or all, and Georgia gave an extensive land grant. Three-fourths of the States now have either State universities or public institutions that will soon come to rightfully claim that title. In 1885 the total endowments amounted to

* *American Commonwealth*, ii. 617.

† Professor Blackmar.

$50,000,000, and their unproductive property to about $45,000,000. Nearly 70,000 students were in attendance, paying an average of about $25 for tuition. Since the passage of the Morrill Land Grant Act in 1862 there has been a steady development of the system of State universities as the apex of the educational pyramid, and, also, in the lower planes, of more general and effective support of primary and secondary education with more and more thorough and perfect incorporation into the whole educational structure of the State.

THE LAND GRANT COLLEGES of the United States—of the several States, rather—are the product of one of the grandest examples of statesmanlike legislation that the world has yet seen; one second in importance and fruitfulness to no act of legislation subsequent to the promulgation of the Constitution of the United States. Like all great enterprises having for their purpose the benefit of the people by legislative enactment, this failed of complete success through the indifference, the folly, and the absolute stupidity of many of those public servants to whom its operation was entrusted; it has, nevertheless, produced incalculable good, both directly, in the foundation and partial support of technical education, and also partly, and very probably to a vastly greater extent, through its influence upon the States, inducing them to take up and carry on the work from the point at which the General Government left it. It is largely to this legislation that the foundation of the now numerous State universities is due, and the organization of the systems of State education which now more or less completely cover the whole field from primary schools to universities in a large proportion of our States, illustrating the scheme of a complete system of State education to which reference was made and of which the outline was given in the earlier part of this discussion, and more satisfactorily than anywhere else outside of Germany.

The author of the Land Grant Bill, by which colleges of the useful arts were established in every State in the Union at the date of its passage, was Justin S. Morrill, then senator from Vermont, who introduced the bill in 1858, and secured its passage by a small majority, only to see it vetoed by James Buchanan, then President of the United States. But the statesmen who sought thus to perpetuate the strongest safeguard of the nation, the effective education of the people, lost none of their interest or enthusiasm, and persevered in their plan, bringing the bill before

the next Congress and the next, and finally they had the satisfaction of seeing this measure become a law during the administration of Lincoln and in the midst of the dark days of the war. "The genius of Lincoln rose to the occasion. With one hand he smote off the fetters of the slave; with the other he joined in a splendid effort to subjugate nature. On the second of July, 1862, while the announcement of emancipation was still on his desk, he signed the Act of Congress donating public lands for the establishment of colleges of agriculture and the mechanic arts." This was not the first ordinance of the Government in this relation. That passed in 1787, inaugurating the new government of the Northwest Territory, had provided that it should be the first duty of the State to care for education, and in each township a section was set apart for common school education; while a whole township in each State was set apart for the benefit of higher education. The ordinance of 1787 and the Land Grant Act of 1862, the two great acts of legislation which have probably done more positive good in the promotion of the best interests of the people of the United States than any others in the history of our Republic, were signed, the one by George Washington, and the other by Abraham Lincoln. And both had their origin in New England. The educational part of the first was probably mainly written by the Rev. Manasseh Cutler, and introduced and pushed to its passage by the Hon. Nathan Dane, of Massachusetts; the last was mainly the work of Mr. Morrill. The ordinance of 1787 contained a provision forbidding the extension of slavery into the Northwest Territories; the law of 1862 was nearly contemporary with the Emancipation Proclamation. Washington and Lincoln alike promoted education, and, at the same time, repressed slavery.

By this Act of Congress, approved July 2, 1862, it was provided that there should be granted to the several States public lands, "thirty thousand acres for each Senator and Representative in Congress," from the sale of which there should be established a perpetual fund, "the interest of which shall be inviolably appropriated, by each State which may take and claim the benefit of this act, to the endowment, support, and maintenance of at least one college where the leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the

States may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life." The act forbade the use of any portion of the fund, or of the interest thereon, for the purchase, erection, or maintenance of any building or buildings; but the several States claiming and taking the benefit of the provisions of the act were required, by legislative assent previously given, "to provide within five years at least not less than one college" for carrying out the purposes of the act.

The land thus assigned was given in the form of "land scrip," conveying title to the holder of such land as he might locate under the then existing laws for location of public lands held undisturbed by the General Government. No State was allowed to locate this land, but it must sell its scrip and appropriate the proceeds to the prescribed purpose. These proceeds were to be invested, by each State, in safe bonds, bearing not less than five per cent. interest, and the State was bound, in accepting the provisions of the bill, to agree to meet all the costs of securing such bonds, and to hold good or to make good the full amount of the principal of the fund thus appropriated to the purposes of education at all times and under all circumstances; thus making it a "perpetual fund" for that purpose.

In most cases the States complied fully with the terms of the act; some of them more than completely. In the majority of the States the funds were invested either in State bonds or in a special bond made out for this particular purpose by the State and deposited in its treasury, and the returns were either the prescribed five per cent. or something more, in every case except that of the State of New York, which latter State never, until compelled by the courts, complied either in letter or in spirit with the law. Maine and Indiana paid five per cent.; New Hampshire, Vermont, Pennsylvania, North and South Carolina, and Ohio paid six; the funds being paid into their treasuries. Massachusetts was the only State in which the fund was divided; most of the State legislatures deciding at once and unhesitatingly that it would be better to hold the fund undivided and to either give it to some existing institution which should comply with the provisions of the grant, or founding an institution, as Cornell University in the State of New York, in direct compliance with the terms of the law.

The accompanying table, collated from the documents published by Cornell University relative to the suits instituted by or against

MECHANICAL AND AGRICULTURAL COLLEGES.

LAND GRANTS.

State.	Acres Granted.	Realized.		How Invested.	To what College Allotted.
		Total.	Per A.		
Maine	210,000	$118,300	$0.56	State 5%.	State Coll. Agr. & M. A.
New Hampshire	150,000	80.000	.53	State 6%.	" " " " "
Vermont	150,000	135,500	.90	State 6%.	" " " " "
Massachusetts	390,000	219,000	.56	R. R. bonds, 5%.	Mass. Agr. C. (⅔); Mass. Inst. Tech. (⅓).
Rhode Island	120,000	50,000	.41	Br. Univ. 5%.	Brown University.
Connecticut	180,000	135,000	.75	State mtges. in part.	Sheffield Sci. Sch., Yale.
Total New England	1,200,000	$737,800	.614		
New York	989,920	$473,403 / 6,188,071	.53 / 6.20	State 5%. / Private investments.	Cornell University.
New Jersey	210,000	116,000	.55	State bonds, 6%.	Rutgers College.
Pennsylvania	780,000	406,000	.52	State 6%.	Penna. State College.
Delaware	90,000	83,000	.92	State bonds, 6%.	Delaware College.
Maryland	210,000	115,943	.55	State bonds, etc., 6%.	Md. Agric. College.
Total Middle	2,279,920	$7,382,417	3.23		
Total, excepting New York	1,290,000	$720,943	.559		
Virginia	300,000	$285,000	.95	State bonds, 11%.	Va., Ag. & M. Coll. (⅔); Hamp. Ins. (⅓).
West Virginia	150,000	90.000	.60	U. S. P. R. R., 6%.	W. Va. Univ.
North Carolina	270,000	125.000	.46	State 6%.	N. C. Coll. Agr. & M. A.
South Carolina	180,000	191,800	1.07	State 6%.	Univ. of So. Ca.
Georgia	270,000	243.000	.90	State 7%.	Univ. of Ga.
Florida	90,000	155,800	1.73	State bonds, 6%.	State Agric. Coll.
Mississippi	207,920	183.028	.90	State bonds.	Ag. & M. Colleges.
Alabama	240,000	253.500	1.06	State bonds, 8%.	Ala. Polytech. Inst.
Louisiana	210,000	210.000	1.00	State —%.	Tulane Univ. of La.
Texas	180,000	209,000	1.16	State bonds, 7%.	Agric. & Mech. Coll. Tex.
Tennessee	300,000	403.500	1.34½	State bonds, 6%.	Univ. of Tenn.
Kentucky	330,000	200.000	.60	State bonds, 6%.	Univ. of Ky.
Arkansas	150,000	135,000	.90	State bonds, 8%.	Ark. Indust. Univ.*
Missouri	330,000	170,000	.52	State 5%.	Univ. of Mo.
Total Southern	3,207,920	$2,859,628	.891		

Ohio	630,000	$342,451	$0.54	State 6%.	Ohio State Univ.
Indiana	390,000	340,000	.87	State 5%.	Purdue Univ.
Illinois	450,000	450,000	1.00	City bonds, mortg's.	Univ. of Ill.
Michigan	240,000	600,000	2.50	State 6%.	Univ. of Mich.
Wisconsin	240,000	363,739	1.51	State 5%.	Univ. of Wis. (⅛ mill tax = $71,654.)
Iowa	240,000	649,396	2.70	Mortg's, 7%.	Ia. State Agric. Coll.
Minnesota	120,000	526,838	4.39	Mortg's, 6%.	Univ. of Minn.
Kansas	90,000	501,426	5.57	City bonds, 6%.	Kan. State Agric. Coll.
Nebraska	90,000	39,505	.44	Not stated.	Univ. of Neb.
North Dakota	.....	.....	....	State by constitution.	
South Dakota	.....	.....	....	State by constitution.	
Total North Central	2,490,000	$3,813,355	$1.53		
Colorado	90,000	112,500	1.25	Not determined.	Colorado Agric. Coll.
Montana	.....	.....	....		
Idaho	.....	.....	....		
Washington	.....	.....	....		
Oregon	90,000	93,985	1.03	Mortg's, 8%.	Corvallis Coll.
California	150,000	771,687	5.14	State mortg's, in part 7%.	University of Cal
Nevada	90,000	95,000	1.05½	State bonds, 4%.	Nev. State Univ.
Utah	.....	.....	....	U. S. bonds, 4%.	
Arizona	.....	.....	....		
New Mexico	.....	.....	....		
Total Far West	420,000	$1,073,172	$2.56		

SUMMARY.

New England	1,200,000	$737,800	$0.614	Michigan, Colorado, Kentucky, and Louisiana had not yet sold all their land in 1890, and the probable receipts from the lands unsold are estimated in the above table. Colorado still holds nearly its whole land grant, which is estimated at $1.25 per acre, though the land which it has already sold has brought less than that sum. Eight of the newer States (and remaining Territories) had made no disposition of their land grant in 1890, and we believe most of them are still holding the grant.
Middle	2,279,920	7,382,417	3.03	
" excepting New York	1,290,000	720,943	0.559	
Southern	3,207,920	2,859,628	0.891	
North Central	2,490,000	3,813,355	1.54	
Far West	420,000	1,073,172	2.56	
Total United States	9,597,849	$15,866,372	$1.60	
" " less New York	8,607,920	.....	$1.07	

* With $130,000 more of county and city funds in consideration of location.

that institution, exhibits the distribution and disposition of this great fund by the several States.*

But in the majority of the States the gift of the General Government has proved to be but the beginning of a system of aids to the promotion of education, and especially of the education called for by the people, in which the States themselves have taken effective part; and the royal gift of the nation of 1862 has been fully equalled by the contributions made by the States to the same great cause. In nearly all the Western States this reinforcement of the action of Congress by the legislation of the State has resulted in the organization of State universities which, though to-day young and with much to be done to make them complete even in form, are accomplishing a grand work among the people. New York and the Eastern States have done comparatively little; but the people of those commonwealths are peculiarly fortunate, in the one case in the possession of the best-endowed university west of the Hudson River; in the other, in having the older universities in their midst, with their growth in means and culture giving them the fruits of a century or more of progress. The educational structure of these United States is yet crude as to form, incomplete in its details; but it is the foundation and the framework of an edifice which we may well hope and believe will become in a few years all that our people can desire. This is in accordance with the contract made by the States accepting the land grant with Congress. The provisions of the statute required the recipients of this great grant to provide for the perpetual care of the capital of the fund, and for the payment of all taxes and premiums and costs whatsoever, that that capital might remain forever and absolutely unimpaired, and to see that it should not even be expended for buildings and equipment of the colleges of agriculture and the mechanic arts which the States were bound to provide as the condition of its receipt. But the States have, in many cases, and especially in the West, done far more than this, and have often supplemented the liberality of the Congress by contributions from their own treasuries of equal and sometimes of larger amount. The Congress of the United States and the legislatures of the several States have thus worked together from the days of the ordinance of 1787, and the magnitude of the total of

* *Engineering News*, July 14, 1892. *History of the Agricultural College Land Grant Fund of July 2, 1862.* Ithaca, N. Y., 1890. Published by Cornell University.

these appropriations is probably quite unimagined by the average citizen. Between the date of the organization of the States into a nation and the year 1862, the Federal Government had set apart no less than 140,000,000 acres for the promotion of the education of the people. What wonder that the people of the United States are looked upon as the most intelligent, as a nation, in the world of men! This constitutes a real nationalization of education, and the basis for a final and complete organization such as is presented as the subject of the ideal, the dream, perhaps, of the earlier part of this paper. It is the first instance in the history of the world of so extended, extensive, and democratic—republican, if you wish—a system of education of a people. It was the approach of a culmination of that movement which, away back in 1824, began the agitation in favor of manual-training schools for the people, which, in 1783, had opened the halls of Harvard University to the students of the science of chemistry, and which inspired the founders of the scientific schools of that great university, and of Yale and Columbia, and the builders of the Rensselaer Polytechnic and other detached schools of applied science. The donation of 1862 from the Federal Government amounted to above 9,000,000 acres, and the total from the United States contributed to this great cause in a century has risen to about 150,000,000, to which, also, must be added the value of the special appropriations, as by the "Hatch Bill" of 1890, giving the income on millions of dollars besides to these previously founded State colleges.

An enormous loss was sustained in nearly all the States, usually through either culpable negligence or ignorance or in consequence of serious misunderstandings of the law and of the proper methods of securing the maximum returns from sales of the rights conferred. Rhode Island obtained but 41 cents an acre for its comparatively small allotment; eleven other States sold their rights for from 45 to 60 cents, although the value of government lands had been for many years held at $1.25 an acre, and their intrinsic value was constantly rising. Nine States obtained, by careful management, securing titles to land within their own borders, amounts ranging from $1.34 to $5.57 per acre.

New York presents a very peculiar case; its State government sacrificing its lands at the rate of 53 cents an acre, until, at the earnest solicitation of Mr. Cornell and his friends, that statesman and philanthropist was permitted to buy the scrip remaining,

with the agreement that he would make a free gift of all his profits thereon to the university to be founded by the State as a "Land Grant College" and given his name. The sum thus realized by the cause of education in the State of New York, in spite of the maladministration of the fund and through the wisdom and generosity of Ezra Cornell, amounted to above five millions of dollars; and that State, in its agricultural and mechanical colleges, profits thus enormously by his foresight, holding to-day about one-half of all the sums realized from the gifts of the United States to the several States for this great purpose. For the privilege of thus aiding the State of New York, and of giving it these millions of dollars, Mr. Cornell paid the State $500,000 in cash and gave it his homestead farm, and even went so far as to buy off, under a compulsory statute actually passed by the State legislature and signed by the governor, for $25,000, the lobbying friends of another scheme. This last amount, it should, however, be said, was later returned to him by the State, but was at once transferred by Mr. Cornell to the treasury of the new university. For all this and untold labors in the location of the lands, unknown losses in their retention for many years, and for detraction such as few men have ever known, even among philanthropists, Mr. Cornell was paid the compliment of a name. The agricultural and mechanical college thus organized by the State of New York in compliance with the terms of the Morrill Bill, was called Cornell University; and thereafter its benefactor gave his time, thought, strength, and life to the furtherance of the great work to which he had given his wealth. He died in comparatively moderate circumstances, and almost his last act was the signing of the documents conveying to the trustees of the State College the property which he had so long, so anxiously, and so successfully managed in its interest. It is the fund thus realized, apart from the first sales of the scrip by the State, which now constitutes the principal endowments of the Land Grant College of the State of New York. It is specifically known as the Cornell Endowment Fund, and is held apart, under the decisions of the courts, as a gift from Mr. Cornell.

We shall see later what are the immediate and visible results of that wise policy of the state which was approved by Washington and by Lincoln.

The United States has, as a nation, been famous throughout the world for its system of free public schools. In all portions

of the country, irrespective of State boundaries, the children are usually offered a primary education, in the most essential branches required by the "industrial classes," free of charge for instruction, and, in many States, are given their text-books by the State itself. In some States this primary education is compulsory, and throughout the country the people take full advantage of their privilege in this respect. But this primary education, until recently, has only extended to the sub-collegiate schools, and although in all the States schooling is free up to and including the high schools, which are usually also the fitting schools for the colleges and professional schools, comparatively few scholars rise from the primary into the secondary and normal schools.

There is, nevertheless, a considerable and rapidly growing proportion of young men and women of the classes denominated industrial who desire and seek higher education and, often, a professional training. Our engineering schools are especially the goal of the young men, and they are, in many cases, usually through the aid of the State, offering free instruction in all branches of study in their curricula. As illustrating the extent to which the State is beginning to assume the duty which, in the introduction to this discussion, it was asserted must be taken as constituting an essential part of a complete system of education of the people, the following table is presented.

The United States expended, according to the census returns, for education in public schools, in 1870, $63,000,000; in 1880, $78,000,000; in 1890, $140,000,000. Per capita, these figures become $1.64, $1.56, and $2.24. In 1890, $100,000,000 were raised by local, and $26,000,000 by State, taxation.

TUITION FEES AND LIVING EXPENSES.

	Yearly Tuition.	Diploma & Grad. Fee.	Living Exp., est.
R. P. I.	$200	8	$300–500
Harvard	150	.....	159–439
Yale	155	10	160–640
Dartmouth	66	.....	300–325
Do. Thayer	75	.....	300–325
Union	$90 (incl. r'm.)	12	190
U. Mich.	35	10	300

(Michigan students $25; matriculation fee of $25 or $10.)

NOTE.—Where a tuition price is given in parenthesis opposite "Free" it means that tuition is free to residents of the State or city only, and otherwise charged as stated.

TUITION FEES AND LIVING EXPENSES.—*Continued.*

	Yearly Tuition.	Diploma & Grad. Fee.	Living Exp., est.
Br. P. I.	$40	.....	
Pa. M. A.	....	.....	$520 all told.
Columbia	205	$25	260–400
Wash. & Lee	75	... ..	135
($12 per mo. bd. in Univ. bldg.)			
M. I. T.	200	.....	240–320
Lehigh	Free*	.....	225–340
U. Va.	142	.....	158–258
(To Virginians, $92 tuition.)			
Cornell	100	5	200–325
(Over five hundred free scholarships.)			
Tufts	100	.....	152–269
U. Ga.	34.75	.....	108–160
Lafayette	111	None	150
Wash. U.	150	5	215–330
U. Vt.	60	.....	120–200
Kans. Agr. C.	Free	.....	100–200
Worc. P. I.	150	.....	200+
(Free to rest of Worcester Co. under 21, and to 20 other Mass. students.)			
Ala. P. I.	Free	.....	
Me. Agr. C.	30	.....	150–200
U. Pa.	200	20	150–210
Stevens	150	.....	250–450
(If residing in N. J. while a student; otherwise $75 more.)			
U. Mich.	Free (8)	.....	120–200
Swarthmore	200	.....	250
($100 less for children of Quakers.)			
U. Mo.	40	5	130–200
($1.75 per week all told in club-house.)			
U. Cal.	Free	.....	150–250
U. Kans.	Free (10)	5	150+
U. Minn.	Free	.....	200–275
Rutgers	75	7.50	175–300
(Forty free N. J. scholarships.)			
U. Ia.	25	5	225
Cornell Coll. Ia.	36	.....	92–153
U. Ill.	Free	.....	137–227
U. Cinc.	Free (60)	.....	
Princeton	120	12	171–505
.....	.....	.....	Mean, 397
U. Neb.	Free	5	150–450
Colo. S. M.	Free	.....	200 280
W. U. Pa.	100	5	180
Pa. S. Coll.	Free	.....	200+
Purdue	5	.....	120+

* A tuition fee ($100, we believe) has recently been established.

TUITION FEES AND LIVING EXPENSES.—*Continued.*

	Yearly Tuition.	Diploma & Grad. Fee.	Living Exp., est.
Rose P. I.	75	.....	200
Mich. M. M.	Free	.....	160
Mich. A. C.	Free	5	100–126
Ga. S. Tech.	Free (150)	.....	
Va. Mil. Inst.	Free	.....	365 all told.
(For State cadets $165 all told.)			
Vanderbilt	55	.....	110–180
U. City N. Y.	100	7	
U. No. Ca.	77.50	.....	120–210
U. Ala.	Free (40)	3	162.50 all told.
Ohio St. U.	15	5	100–300
Delaware C.	60	.....	160+
State C. Ky.	Free (20)	.....	143–163
Haverford	150	.....	200

This table, which was collated for 1892 by the *Engineering News*, exhibits the remarkable fact that a very large proportion of the colleges and schools of engineering of this country are offering higher education without charge to every citizen. This is not only the fact as to the citizens of the States in which these institutions are situated, and within the States thus defraying the enormous expense of such instruction; but, in most cases, the citizen of any State may attend the sessions of the college classes of either of these institutions. Another interesting fact is to be noted in this connection: The States which most generally and liberally sustain free higher education are those which are most democratic and most inclined to promote the interests of "the masses" as against the encouragement of the conditions favorable to the aggregation of wealth and the establishment and continuance of "the classes." It is in the western and southern States that we find higher education freely offered to the poorest of their citizens; it is in the eastern and New England States that we find the State doing less, the citizen doing more, for college and university work. It thus happens that, although at the moment the greatest facilities and the highest courses are found in the latter, the time is evidently rapidly coming, unless a great change soon takes place in the methods of the older States, when liberal State aid, by regular and stated taxation—by which the former are now enlarging, elevating, and amplifying in all ways their State university work, which is developing the State universities of the

West and South—will result in giving the newer portions of the country facilities for education such as the world has never yet seen, and vastly superior to those only obtainable at present, in the East, through the sporadic and spasmodic, and hence always uncertain, unsatisfactory, and inefficient aid of individual philanthropy. As in every other business, it is only by ample capital, a regular income, a permanent organization, and the ability to secure and to hold the best men for the work, that higher education can be made thoroughly successful.

The importance of the State universities and the value of institutions which tender free higher education, and even in some instances professional education, to the poorest of the citizens of the commonwealth, need not be discussed at length. The number of young men—and of young women indeed—now seeking such education is large and daily increasing; but there are comparatively few who can find means of self-support during the long period of primary and secondary education and preparation, to say nothing of meeting costs of instruction; and, although they are often willing—compelled, in fact—to live with a frugality approaching actual suffering, occasionally even passing the line, many fail to reach their goal. Every dollar which can be saved them in this long and arduous race is an aid to the State; for it enables the community to profit by talent, strength of character, mental discipline, possessed by this class to an extent unapproached by any other body of young people in the community. The writer has known of young men living on sixty cents a week, and of many supporting themselves while in college on a dollar and a dollar and a quarter a week, depriving themselves of all but absolute necessities, of necessities even, to secure a college or a professional education. It is of such stuff as this that the most desirable citizens are constituted. It is by the facilitating of the admission of a larger proportion of this class to the constructive and to the so-called learned professions that the State universities of this country will undoubtedly do most to promote the best interests of the whole people.

The aid of the State is essential to the complete and permanent success of the higher education in any community. This proposition becomes sufficiently evident when it is considered that it constitutes the apex of the pyramid, must be firmly and intimately based upon and connected with the secondary education of the community, and that in turn must be similarly united with and

built up on the primary education which is at the base of the whole edifice. Further, that constant and effective and reliable support which higher education, even more than the lower grades, must be assured, can only be furnished by the state. The colleges and universities which depend upon private endowments and support are not only always in need through the operations of natural growth, but, although often richly endowed, invariably receive such additional aid as they thus obtain at irregular and uncertain periods, and usually absolutely irrespective of their crises of need. That essential element of permanent and highest success—regular, ample, and certain income—can only be insured by the state and through a fixed and positive system of legal appropriation. Every great and famous university in Europe stands upon such a basis of state aid; every college and university in the United States, having no such backing, is in constant difficulty from the entire independence of its income and its necessary expenditures. This is the case even with institutions like Cornell University, for example, with its millions invested. Not only do its opportunities widen faster than its income increases, but its varying income has absolutely no even approximate relation to its needs. The larger universities of this class, which are mainly in the East, are always needy, and the wealthier they are the more needy are they; as it is invariably the fact that they expand as rapidly as physically possible, and endowments provided, however largely, find even more prompt and more effective application than in the smaller colleges. They afford the largest and most efficient opportunities for philanthropic investment, but rarely are given enough in any one endowment for the purpose specified as that to which such endowment is to be applied. Their "general funds" are invariably depleted to bolster up the temporary or permanent needs of endowed departments, and the trustees are always embarrassed by deficiencies in the general account. Only those institutions which receive ample and regular income from the state for the regular and essential expenditures, and in which private munificence finds its field in adding the desirable but unessential, the comforts and the luxuries of higher intellectual life, are certain of permanent and satisfactory success in their most vital work. The tendency toward a support of the universities, their foundation and adoption, by the State, as illustrated now so generally among the States west of the Hudson, is thus obviously to be

regarded as one of the most encouraging and reassuring signs of the times. These States are carrying into effect the plan of education of the people for the work of the people which must constitute a main element in our future progress. They are also taking the course and adopting the plan which was sketched by the writer, years ago, in his plan for New Jersey.

The great technical associations of the United States have done much to promote the extension and perfection of the system of education which has come to characterize this generation by its growth and product. There are four principal societies of this class, distinctively national in extent of constituency:

American Society of Civil Engineers, of 1,700 members.

American Institute of Mining Engineers, with 2,500 members.

American Society of Mechanical Engineers, with 1,700 members.

American Institute of Electrical Engineers, with 700 members.

These were founded, respectively, in 1865, 1871, 1880, 1886, and have steadily grown in influence and fruitfulness as well as in numbers. Their lists of honorary and active members contain the names of not only all the prominent and successful engineers of the day, but also many foreign engineers of distinction. These numbers do not strike one as very large when comparing them with the six thousand members of the British Institute of Civil Engineers, or the similarly large body known as the Verein Deutsche Ingenieure; but for their age and time they are satisfactory in all respects to the members of either. They all publish transactions, usually in separate papers or in monthly issues, which are, each year, bound up in the annual volume. Some of the very best work done in this country will be found described in these papers, and the quality of the transactions of American engineering associations is such as to compare very favorably, if not such as to sustain an award of superiority, when placed beside those of other countries. They are of such importance as to be sought with the greatest eagerness by all the great public and other libraries, and by the practitioner, as furnishing the best possible collection of accounts of current and standard engineering practice throughout the country.

The annual meetings and the frequent intermediate gatherings of these societies and of their scattered members, either at headquarters or in widely separated localities, as society meetings or as sections of the main body, have done more to aggregate and make solid and homogeneous the various branches of the en-

gineering profession than all other conditions beside. They have made the fact manifest that engineering has come to be a profession, and, more than that, a learned profession, demanding more of its novices and compelling a more rigid and exacting course of preparatory study of those seeking to enter its higher fields than any other existing profession. The engineering schools throw out at least one-third of all who enter them, condemning every weakness as well as every fault of the aspirant, and the accidents of life very generally throw out another third. It may be well doubted if as many as one-third of all the young men who at sixteen are looking forward to entrance into the profession through scientific preparation actually reach the goal. Of these, again, all who desire to become admitted to the engineering societies and be thus given formal admission to the organized professional body must pass the test of official scrutiny by the boards of direction and the test of the vote of admission by their fellows. The fact that a single school of engineering is now graduating one hundred young men annually, and that all these societies together only number six thousand six hundred members, is evidence of the exacting nature of these systems of sifting and rejection of unsatisfactory candidates for indorsement by the profession.

THE FIRST OF AMERICAN TECHNICAL SCHOOLS, strictly speaking, was founded at the very beginning of the century. This was the Military Academy at West Point, N. Y., and the movement of which it was the outcome began some time in the early days of the Revolutionary war. The Continental Congress appointed a committee as early as October, 1776, "to prepare and bring in a plan of a military academy," but, although frequently urged by President Washington, nothing was actually accomplished until after his death. In 1802, Congress authorized the formation of a corps of engineers which should be stationed at West Point, and there "constitute a military academy." It was to consist of sixteen to twenty officers and a small body of cadets. The academy was opened July 4, 1802, with ten cadets. Its first graduate was Gen. J. G. Swift, who acquired a reputation at once, became later the Chief of Engineers, and died at the age of eighty-two in 1865.* Its course included mathematics as far as trigonometry and the applications in surveying and stereotomy; the only modern language taught was French; and the rest of the curriculum seems to

*See *The Early History of West Point*, by General Cullum, for an account of this foundation and the work of its early years.

have been made up of instruction in the art of war and mainly in the "school of the soldier." In 1811 there were only one professor and nine cadets; notwithstanding the fact that the law of 1808 had authorized the appointment of one hundred and fifty-six. In 1812 there were but thirty-six. In that year Congress authorized the appointment of a total of two hundred and sixty.

In 1816 there were two hundred cadets at the school, and the present system of four classes was formally established, and the uniform adopted. In 1817, the appointment of General Thayer—then colonel—to the superintendency initiated a rapid growth in effectiveness which was never again lost. Of his administration, General Cullum remarks:

"In this brief sketch it would be impossible to record each prominent event in Thayer's management, and to descant upon the multiform meliorations introduced by him during the sixteen years of his masterly administration, wherein he built up the Military Academy from an elementary school to a model seminary of science and soldiership worthy of a great people. In these sixteen years, mathematics, from Hutton's elements, had advanced to a complete course of algebra, geometry, plane and spherical trigonometry, descriptive geometry (including shades, shadows, and perspective), surveying and the use of instruments in the field, analytical geometry, and differential and integral calculus. From a little smattering of French, taught to a few in 1817, some in 1833 became sufficiently proficient to speak the language, most to read it fluently, and all to translate readily scientific text-books and professional works. Drawing, confined mostly to copying a few traces of fortifications and a slight use of the brush, had progressed to the delineation of the human figure, pen and pencil landscapes, and topography in all styles of representation. Natural and experimental philosophy, from what is to be found in Enfield, had grown to an extended course in physics, dynamics, hydrostatics, hydrodynamics, magnetism, electro-magnetism, optics, and astronomy, embracing their principles, phenomena, and use of the various instruments. Chemistry, mineralogy, and geology in all their branches had been introduced in 1820. Artillery, from a few elements given in a small treatise, with a little target practice and the manual of the piece, had expanded to the theory and practice of gunnery, the fabrication of pyrotechnics required for all the purposes of war, and the manœuvre of pieces and foot batteries. Grammar, rhetoric, geography, history, moral philosophy,

and constitutional and international law had been added in 1818 to the duties of the chaplain. Engineering, just beginning to be taught as in the Polytechnic School of France, had been enlarged to the broad basis upon which was built subsequently the admirable course of field and permanent fortifications, the science of war, architecture, stereotomy, and civil engineering in all of its branches. Infantry tactics, confined chiefly to elementary drills in 1817, comprised, in 1833, the theory and practice of all movements from the school of the soldier to evolutions of the line, including the exercises of light infantry and riflemen. Military police, in camp and barracks, was carried out to the full extent required by army regulations. Numerous summer marches had been made, extending even as far as Boston, but were abolished after 1822.

"The peerless superintendent was relieved, July 1, 1833, from command of the Military Academy, which, in the sixteen years of his devoted administration, had grown from a badly conducted rudimentary school to become a preëminent seminary of science, and enduring monument of his fame, a fostering mother to the whole army, the cynosure of all educational institutions throughout the land, and a priceless possession for the nation's security and glory."

The United States Military Academy at West Point for many years supplied not only the educated officers of the army, but also a large proportion of the engineers in civil life throughout the land. The later institution of good technical and engineering schools, capable of more than meeting the current demand, has, in recent years, checked this deflection of army officers from their originally selected careers; but it still remains the fact that West Point contributes a very sensible proportion of the profession in civil life now engaged in the conduct of important engineering work, and especially in internal improvements. The school has preserved a reputation for severe and profitable training, and the physical powers of its graduates, due to their regular and continued drill and gymnastic training, give them special advantages over their competitors educated in civil life. The present organization of the academy is as follows: *

* *Engineering News*, April, 1892.

ORGANIZATION OF THE ACADEMIC DEPARTMENTS OF THE WEST POINT MILITARY ACADEMY.

Department.	Value in Merit Roll.	No. of Instructors.
1. Natural and experimental philosophy	300	5
2. Modern languages	300	8
3. Drawing	125	4
4. Mathematics	400	9
5. Chemistry, mineralogy, geology	225	5
6. History, geography, ethics	75	3
7. Civil and military engineering	300	4
8. Law	150	3
9. Practical military engineering	None	3
10. Military tactics (drill regulations)	100	9
11. Ordnance and gunnery	125	3
12. Master of sword	....	1
13. Discipline	200	..
Grand total	2,300	57
Total for civil departments (Nos. 1 to 8)	1,875	42
" military departments (Nos. 9 to 12)	225	16
" discipline (No. 13)	200	..

Note.—Last year (1891) a merit value of 45 was given to "Practical Military Engineering," making the present grand total 2,345 instead of 2,300, as shown above.

The United States Naval Academy, the second of the two great technical schools sustained by the Federal Government, was founded by Act of Congress in 1845, receiving its first classes in October of that year. Instruction had previously been given midshipmen either on board ship—usually by the chaplain—or at the navy yards of New York, Philadelphia, Boston, and Norfolk, by a corps of, at that date, twenty professors and teachers, of whom two-thirds were at sea. Secretary George Bancroft, by regulations published by the department, concentrated this force, and formed a school which was subsequently formally authorized and established by Congress, as above. It was located at Annapolis, Md., at an old army post, Fort Severn, subsequently turned over by the War Department to the Navy. During the Civil War the academy was temporarily removed to Newport, R. I., returning to its old home in the autumn of 1865. The school has always had an excellent curriculum as well as admirable professional course, and its graduates have proved themselves competent to keep pace

with the science as well as the art of their profession in its, of late, extraordinarily rapid progress.*

The school has a fine equipment both professional and scientific, a very excellent library, especially rich in its mathematics; and these and the presence of sailing vessels and steamers, assigned to the academy for the purposes of instruction, altogether, give this institution a most complete and unique outfit for its purposes. Immediately after the close of the war, and later, it turned out classes, annually, of fifty or sixty, sometimes more, and of an average ability and working power probably much superior to the average civil school. It is only strong and scholarly young men who can pass the stringent examinations and do the work demanded of midshipmen at the academy.

THE LAWRENCE SCIENTIFIC SCHOOL is the technical department of Harvard College. It was founded in 1847 by Mr. Abbott Lawrence, its inauguration being effected by a gift of $100,000, and through legislation of the university of which the following is the enacting clause: "There shall be established in the university an advanced school for instruction in theoretical and practical science, and in the other usual branches of academic learning, to be called The Scientific School of the University of Cambridge." The name was subsequently modified by adding the name of the donor of its endowment. Its first professor was Louis Agassiz; its second, Eben Horsford. The stated purpose of the founders was that of providing instruction in the natural sciences, especially in their practical applications, and in engineering. But that purpose was not, for many years, fully carried into effect; nor was the founder himself greatly honored by the institution which he thus placed, so far as he was able, in the van of that great movement which we are now studying. Even his name does not appear in the annual catalogues of Harvard University, and it is for a stranger a difficult matter to ascertain to what member of the family the Lawrence Scientific School owes its origin. The authorities of that great university were

* During a period of six years' service, in the course of a somewhat extended connection with the United States Navy, the writer enjoyed the pleasure and profit of experience and observation of the workings of this school; and twenty years of later service, since his resignation, in the technical schools of civil life, have left with him the impression that the combination of physical, scientific, and general training with the professional work of the naval school furnishes the most admirable example of an ideal method of education that can be anywhere seen. Probably the same may be said of the Military Academy at West Point.

sadly derelict in this matter. It was specifically provided and enjoined by the founder of the school that it should be devoted to the purposes of a professional school, especially in engineering. As he stated it: "The three great practical branches to which a scientific education is to be applied are: 1st, engineering; 2d, mining, in its extended sense including metallurgy; 3d, the invention and manufactures of machinery." In other words, the Lawrence Scientific School was to be a school of engineering, and the funds which have been until recently misapplied were intended to be devoted to that purpose. The intent of Mr. Abbott Lawrence, in 1846, was to organize a school of precisely the same character as those contemplated in the Morrill "Land Grant Bill" passed by the United States Congress nearly twenty years later, in which "the leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education of the *Industrial Classes* in the several pursuits and professions in life." *

In his letter of instructions, which was absolutely and amply specific, Mr. Lawrence says: "Mathematics and chemistry, geology and mineralogy, and the other sciences investigating the properties and uses of materials employed in the arts; carpentry, masonry, architecture, and drawing, are all studies which should be pursued to a greater or less extent in one or all of these principal divisions." It was with such exact definitions of its responsibilities placed before it by the intending benefactor of coming generations of young men entering the constructive professions and vocations, that the university thus advantaged as explicitly "pledged its best efforts to carry faithfully into execution these enlightened suggestions." The school was, however, always managed mainly as a school of pure science, and has not even yet fairly commenced the work set before it and the university by the instructions of the founder and the pledges of the college. But, in spite of the fact that its support was of that character, its department of engineering was its principal section for twenty years, graduating a half to two-thirds of classes turned out each year,

* An Act donating public lands to the several States and Territories which may provide colleges for the benefit of agriculture and the mechanic arts, July 6, 1862.

numbering usually ten or twelve, and, as a maximum, sixteen; the total for its history to 1892 being 265, of whom 155 were in engineering. In the succeeding twenty years and to date, the numbers graduating have been usually two or three. But a marked change of policy seems to have taken place within the past year or two, and the introduction into its faculty of a larger number of men, strong in applied science and in engineering, and the strengthening of the school in all practicable ways, may be expected to soon place it where it belongs * among the schools of applied science of the country. So far as external conditions affect it, none in the United States has a larger opportunity or more encouraging outlook than the Lawrence Scientific School of Harvard University.

THE ENGINEERING SCHOOLS OF THE UNIVERSITY OF MICHIGAN were among the early technical schools of the United States, having been authorized, although not fully established, at the organization of the university in 1817. The civil engineering branch was not in operation, however, until 1852; and the first diplomas were issued in 1860, two students then graduating with the degree "C. E." According to our best authority on this subject, the school was thus the sixth to send out educated engineers. The original charter of the college was created as that of a true State university, and the taxes of the State were increased 15 per cent. to meet the

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* "The three great practical branches to which a scientific education is to be applied amongst us are, 1st, engineering; 2d, mining, in its extended sense including metallurgy; 3d, the invention and manufacture of machinery. These must be deemed kindred branches, starting from the same point and gradually diverging to their more special applications. Mathematics, . . . chemistry, . . . geology, mineralogy, . . . carpentry, masonry, architecture and drawing are all studies which should be pursued to a greater or less extent in one or all of these subdivisions. . . . I cherish a wish to see the observatory . . . ready for use, and do not intend to interfere with (the accomplishment by others of) this great object. Nor do I mean to occupy the ground of another branch of science that will, I suppose, at a future time, present strong claims upon the public bounty. I allude to natural history. I beg to suggest further that the whole income of this school be devoted to the acquisition, illustration, and dissemination of the practical sciences forever. . . . I now leave the whole subject in the hands of the gentlemen composing the Corporation." (Letter of gift of Abbott Lawrence, June 7, 1847.)

"It is deemed by the Corporation a high privilege, and a great reward for their labors, to be the stewards of such bounty; and they pledge their best efforts to carry faithfully into execution the enlightened suggestions with which the letter accompanying the donation is filled." (Resolution of acceptance by the Corporation of Harvard College, June 7, 1847. For both documents in full see *Engineering News*, May 5, 1892, pp. 460-61.)

anticipated costs of its operation in a commonwealth of only 7,000 or 8,000 people. The original location was at Detroit. Its present charter was written in 1837, and the university then took its existing form, and a moderate taxation established for its benefit in place of the former fixed income. The university received the proceeds of the Michigan Land Grant of 1862 from the United States, and the State has itself contributed a total of not far from two millions of dollars for its support and extension; the two sources of supply together giving a total of about three millions.

The Sheffield Scientific School of Yale University had its origin as one of the departments of Yale College at a very early period in its history. The college was chartered in 1701 by the first "General Assembly" of Connecticut as "the collegiate school" of the State. Its first board of trustees consisted of ten clergymen. It was located at Saybrook, removed to New Haven in 1716, and rechartered as Yale College in honor of Elihu Yale, who gave it property valued at £200 in 1718. The Scientific School was organized in 1847, and in 1860 and later was given an endowment of $100,000 by Mr. Joseph E. Sheffield, for whom it was then re-named. The school received the Land Grant Funds coming to the State in 1863, and has had considerable accessions of funds and property since, including the recent large bequest of Mr. Fayerweather. Its work has always been upon a high plane, and very successful in both applied science and constructive engineering. A whole academic faculty, and that of the university, are available to supplement its work; while the School of Fine Arts, founded by Mr. Street, is another auxiliary of very great importance. Yale University has always been especially strong in the applied sciences and peculiarly successful in the departments offering that line of work to their students. The following table gives the data relating to the graduates in engineering to 1885:

Class.	Mining Eng.	Dynamic Eng.	Civil Eng.	Total.
1868	2	1	7	10
1869	3	..	11	14
1870	1	..	15	16
1871	..	2	13	15
1872	Missing	..	..	..
1873	..	10	9	19
1874	..	6	17	23
1875	..	9	22	31
1885	..	16	17	33
Total for the 8 years mentioned				161

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY was organized and in operation as early as 1864–5, graduating its first students in 1868. Its charter was created in March, 1861, and after several years of earnest agitation in favor of the foundation by the State of an institution which should be devoted to instruction especially of "the masses of the people engaged in industrial occupation," in order that they might more effectually "avail themselves of the advantages to be derived from the labors of those who are wholly devoted to purely scientific research."

This movement was a popular one; and it was led by many of the foremost citizens of Boston and of the State of Massachusetts, and the act of the legislature in creating the new school was purely in deference to the mandatory action of the people of the State, its constituents. In this respect, the foundation of the institution was unique. The same public spirit which compelled its organization has ever since sustained it, and its work has been of that high character which should be expected of an institution of learning founded under such circumstances and amidst such a people. Two-thirds of a city square was granted for the use of the institute, and this land has now been covered with buildings, and other property acquired in the neighborhood for the further extension of the school; while immediately around it are grouped a remarkable cluster of public buildings devoted mainly to scientific purposes. The Massachusetts assignment of the Land Grant of 1862 from the General Government was, in part, turned over to the school, and it has received occasional aid of importance from the legislature; but its endowments have been mainly private and small and its income principally from tuition fees.

The first class numbered 13, and the first catalogue contained a list of 72 students (1865–66). The courses were intended to provide instruction "suited to the various practical professions of the mechanician, the civil engineer, the builder and architect, the mining engineer, and the practical chemist." Optional, elective, and special courses have always been permitted, to meet the demands of the many students desiring to spend a limited time at the school or to work in special fields, either as matter of choice and special interest or talent, or as compelled by limited financial ability. Working laboratories and workshops in which the principal trades are taught constituted from an early date a characteristic of this institution, and undoubtedly were an important element of a success which has always marked its history. Its buildings

and equipment are reported to be worth about a million of dollars, its invested funds between one-half and three-quarters of a million, by far the largest part of both being contributed from private sources.

Still another direction of the work, in the effort to prepare a people to compete most intelligently and effectively in the markets with those whose products, both of skilled industry and artistic talent, command the richest return for time expended, has its best illustration in the State of Massachusetts.

Under the law of 1870, which authorized any city or town to establish schools of instruction in industrial and mechanical drawing, this movement was initiated by the Boston Public School Committee and Officers with a view to improve the system of instruction in drawing, and by the State Board of Education.

At the very outset it was determined to secure the services of a thoroughly well-educated and systematically trained drawing master; and correspondence with the director of the School of Art at South Kensington, London, led to the appointment of one of its graduates—Prof. W. Smith, at the time Art Master at Leeds—as Director of Art Education for the State.

The organization of a system of art education was commenced by the director and his co-workers, in the autumn of 1871. The establishment of a *State Normal Art School* at Boston, which was intended to be the highest school of art and the source from which instructors were to be drawn, took place in 1873; and the system of art instruction soon extended to nearly every city and town of note in the State. The normal school beginning with 133 pupils increased at a very rapid rate, and its progress in other respects has been gratifying as in attendance.

Annual exhibitions of the State Normal Art School and of the other art schools of Massachusetts have done much toward making the people familiar with the character and the importance of the work and in awakening them to an appreciation of the value of systematic instruction in the application of art to industry. They have had the additional and not less useful result of producing a general improvement of taste and of critical judgment in art matters, which leads not simply to the refinement and elevation of the character of the people, but also to the opening of a market which, once opened, will rapidly grow in its capacity for absorbing art products.

As all the towns affected by the law are now supporting teachers of industrial drawing, these exhibitions include contributions from all directions and, in many cases, contain most admirable work. Some of these original designs for lace, for carpeting, for tiling, and for pottery would be considered creditable to designers and artists of established reputation.

The importance of the work of the Art School, and especially in developing a taste for, and native skill in, drawing, has always been recognized. The French Imperial Commission, some time since, remarked on this point: "All these considerations have led the Commission to propose that drawing, with all its applications to the different industrial arts, should be considered as the *principal* means to be employed in technical instruction. Drawing is, in all branches of industrial art, a means so evident, so useful, and so indispensable for embodying the conceptions of the mind, for studying and fixing the forms to be given to productions, that there can be no need of insisting on the necessity of developing that branch of industry. This necessity, which has long been deeply felt in France, has led to the multiplication, in the great industrial centres, of schools for art and scientific drawing, which have secured to French industry a great superiority in a large portion of its manufactures. Besides the study of artistic drawing, properly so called, that of linear drawing, based on geometrical principles, has also been widely extended in Germany. Descriptive geometry is taught elementarily, and with entirely practical applications, in the drawing classes opened for artisans; there they also acquire the theory of projections. It regards geometrical drawing as a most useful training for the practice of various trades, and as an excellent means of direct demonstrations."

In their report they say of Nuremberg: "In this town, so noted for its various manufactures, there are several drawing schools of different degrees, according to the trades the pupils intend to follow. The first and most important is the higher school of industrial drawing conducted by M. Kroling. It is justly regarded in Germany as the one which has rendered most service to industry." . . . "After attaining proficiency in drawing, the pupils pass on to modelling and sculpture in wood and stone; then, as soon as they have attained a certain degree of skill, they have to compose designs and to model and carve them."

The general opinion is, "that the Nuremberg school has con-

tributed more than any other to the progress of the national industry. This progress is especially manifest in the very decided improvement in the manufacture of children's toys, which are one of the staple productions of the country. For some years past, the improvements in the forms of the articles, whether moulded in clay, or sculptured in wood, with which the Nuremberg manufacturers supply the shops of Paris, has shown us that great progress must have been made in the teaching of drawing."

The American school, like the French *École Centrale*, was founded:

"To encourage the culture of the arts which lead to the union of the beautiful and the useful.

"To aid the professional men who are occupied in the work of national art education.

"To excite emulation among artists whose works, while popularizing the sentiment of the beautiful, and raising the public taste, tend to preserve art industries, menaced by other countries."

THE TECHNICAL DEPARTMENTS OF DARTMOUTH COLLEGE are among the earliest of those attached to institutions of learning of a general character. The college itself was the fourth in order of establishment in the United States, and was incorporated in 1754, at Lebanon, Conn., as an Indian school, and its first president, Rev. E. Wheelock, was also president of the college, when it received its charter and became settled in Hanover, N. H., in 1769. Lord Dartmouth, for whom it was then named, was greatly interested in the college, and it received many benefactions from him. In 1816 it was rechartered as Dartmouth University, and the State assumed charge of its operation. The courts, after an historical and interesting contest between the State authorities and the old Board of Trustees of the college, sustained the latter, and it has remained Dartmouth College to this day. The decision was important as sustaining a private trust against the attempt of a legislative body to overthrow it.

Dartmouth has always had strong men in its faculty, and has graduated strong men in its classes, one of the latter having contributed one-fourth its number to fill professorships and presidencies in that and other colleges. During the generation just past, the college has taken a lead in the promotion of science, pure and applied, and technical education. The New Hampshire Medical College was organized in 1798, and has always held a high position. The modern schools are the Chandler Scientific School,

founded in 1851; the New Hampshire College of Agriculture and the Mechanic Arts, founded as a "Land Grant College" in 1866; and the Thayer School of Civil Engineering, founded in 1867. The first of these scientific schools was founded by Abiel Chandler, a business man of Boston, who gave it a fund for the specific purpose of establishing a school of the industrial vocations, as they are often distinctively called. The College of Agriculture and the Mechanic Arts has the same purpose and substantially the same requirements and methods as other of the land grant colleges, of which more will be said later; while the Thayer School is a post-graduate school in fact, although only so made by the specific and elevated requirements for admission which were prescribed in the deed of gift by which it was established. The three schools are independent, and the cost to the college of their maintenance is thus increased by the necessity of, to some extent, duplicating work; the institution, as yet, not having sufficient magnitude to permit of that completeness of specialization in its faculties which is both desirable and economical in a large university and in a single technical school. The Thayer School probably has the highest course of instruction for its regular students ever yet established in any school of civil engineering, and it is even higher than, probably, the courses laid out for graduate students in many colleges. These schools are all small but efficient, and are likely to grow in magnitude as their excellent work becomes known and, especially, recognized by the professions to which they contribute their aid.

The Worcester Polytechnic Institute is one of the best illustrations of a trade and technical school of high character. As a trade school it is principally designed to give instruction in the mechanic arts, and its work dates from 1868. The method adopted at Worcester is that which gives the pupil instruction in the workshop while still pursuing his studies in the class-room, these studies being principally professional, and the general education and culture of the student being expected to mainly precede or follow this portion of his college life. A beginner works seven hours per day in the shop from February 1st to July 1st; during the remainder of his course he works in the shop ten hours a week, except during July of each year when he works ten hours per day, learning the arts of filing, forging, planing, lathe work, etc., etc., and is taught the construction and fitting up of machinery. There are also employed in the shop regular workmen, whose pre-

cepts and example aid the student, perhaps, quite as much as direct tuition. Thus practice is introduced into every week's work, and it is obtained under the every-day condition of work-shop life and in an atmosphere of business, and the student is also guided by instruction given by an expert mechanic whose principal business it is to give such tuition.

As to the value of this, which has come to be a characteristic feature of every important technical school in the United States, it is perhaps hardly necessary to present testimony ; but the following principles are enunciated by President Gilman in one of his impressive addresses on the modern educations.*

"(1) The value of manual training as a method of improving the brain and nervous system, or, in other words, our thinking apparatus, must be acknowledged.

"(2) The value of manual training as a method of promoting the arts of accurate and precise expression is likewise to be distinctly recognized.

"(3) The value of manual training as a method of preparation for subsequent industrial or professional pursuits—or, in other words, the fact that manual training is antecedent to technical education—is generally admitted.

"(4) The importance of carrying forward manual training simultaneously with all other educational processes must not be lost sight of, so that the brain shall be taught simultaneously by the eye, through the printed page and through every variety of object lesson; by the ear, through every form of utterance, reading aloud, familiar lectures and conversations, the repetition of poetry, and the learning of music, vocal and instrumental; and by the hand, in measuring, matching, marking, and making.

"(5) Universal instruction should be provided in the use of the pen and pencil, and especially in the last named, for drawing is the simplest, most easily taught, and most generally useful of all the fundamental arts of handicraft.

"(6) Among boys, both in the city and the country, instruction should be provided in the use of carpenters' tools. Such tools are simply an expression of the capacities of the hand. To learn how to use them with accuracy is not only a valuable intellectual discipline, it has even moral significance in developing the habits of care, fidelity, thoroughness, honesty, and it makes the posses-

* An address at opening the course of lectures in the winter of 1886-87, before the Industrial Education Association of New York.

sor of the power 'handy' in a multitude of the situations and emergencies of life.

"(7) For girls, the needle is the universal implement, and yet there is no reason why boys should not learn to sew, nor why girls should not learn to use the simple instruments of the carpenter's bench.

"(8) Beyond these subjects—drawing, carpentry, and sewing—there is a boundless field for lessons in metal-working, in iron or brass. Household duties, especially the art of cooking, and the decorative arts of ornamentation and needle-work, may all be introduced if there are competent teachers; but here, again, the lessons should be of general and fundamental character—not as yet special in the line of industrial pursuits.

"(9) Subsequent to manual training come the methods of technical or professional training, and these are as various as the occupations of mankind. But as it is obviously impossible to have technical schools for every human vocation, those subjects which are of general significance and importance first deserve recognition. It is only in exceptional places, where some one form of industry (lace-making, for example, or watch-making) is established, that a very special school is to be established.

"(10) Pecuniary returns are not to be expected from the results of manual training. There must be no expectation that objects are to be made for sale in the market, or that the school is to have its expenses met, in whole or in part, by the work of the pupils. It would be just as reasonable to expect that the compositions of a school-boy, or the drawings of a school-girl, should have a pecuniary value. All such juvenile products are of no value to any one but the owner, and to him only as evidence of efforts put forth with more or less success."

"If these principles are to be enunciated in one statement, this is the truth: Manual training is an essential part of a good education, whether that education be restricted to the common school or carried on to the highest discipline of technical schools and universities."

Columbia College, New York City, established its "School of Mines"—which promptly became the principal American school in mining engineering—in 1863, as the first mining school in the United States. The school was opened in 1864 and graduated its first class in 1867. It grew rapidly, and soon became a general school of engineering, giving courses in nearly all the now usual

branches of professional work. The college itself dates back to 1754, and received its main endowment, as King's College, from Trinity Church. It was renamed and re-chartered as Columbia College, in 1784, and its size and its endowments have continually grown from that date to the present.

The School of Mines was established by the appropriation of college funds for the purpose. It is steadily expanding its work and elevating its instruction, and has from the first been an important factor in the promotion of technical and professional education in this country. Its founders were Professors Joy, Eggleston, and Chandler, and the work of those distinguished men in chemistry, in mineralogy and metallurgy, and in the applied sciences generally, may be taken as the real basis of the prosperity of the school. The two last-named officers still remain on its staff and continue to take part in its management; and the large development of the various schools of engineering and architecture, as well as of that of mining and metallurgy, have given them a body of colleagues of exceptional magnitude and of high efficiency. After the death, recently, of Professor Trowbridge, the professor of engineering, the institution of separated departments of civil and mechanical engineering, and of that now important and rapidly growing branch of the latter, "electrical engineering," brought about an extension of the system of technical departments of the school which permits still larger and perhaps still more rapid development to be expected. As is shown elsewhere in this paper, this great school has sent out not only a larger number of graduates than any other school of mines in the country, but more than all others together. It bids fair to make an advance into the other departments of engineering with great, perhaps equal, success.

The Cooper Institute, of New York City, was one of the earliest attempts to supply technical instruction to workingmen and workingwomen. It was founded by Peter Cooper in 1854 in New York City, and grew steadily in extent and usefulness from the first. Mr. Cooper provided both day and evening classes in primary studies and in trade instruction; giving free tuition in all the elementary branches of mathematical and scientific study, in drawing, painting, wood-engraving, photography, and telegraphy. A large and excellent library affords pleasure and profit to thousands of readers who frequent it. On Saturday evenings through the winter, free lectures are given in the great hall of the Institute, which will seat

about two thousand five hundred people. "The most cherished object of Mr. Cooper's life, early conceived and faithfully carried out, as soon as his means permitted, was the establishment of an institution for the instruction of the industrial classes. He desired to furnish this instruction during their leisure, from work or in the evenings, when they might acquire higher attainments in the practical arts in which they might happen to be engaged, or learn some industrial pursuit which they might desire. Having felt the need of this sort of instruction during his own early and laborious life, and knowing that neither the common school nor the academy and college can supply the technical knowledge and practical education needed by the great mass of youth, Mr. Cooper determined to set an example in supplying this want of a practical education to the working classes that should prove not only useful in his own city, but be contagious throughout the land. He saw, with that wise forecast as well as that broad philanthropy which characterized his mind, that the youth must be trained to industry under an advancing and higher order of work which machinery was introducing." He therefore invested, from 1854 up to time of his death in 1883, about $2,000,000 in this grand enterprise, and had the gratification of seeing, before he died, his plans fully carried into effect, and giving help to thousands of the working-people of his neighborhood.

Peter Cooper left, in this institution, the evidence that he was one of the greatest and wisest of the many great and wise philanthropists that the world has yet produced. The example which he desired to set before his countrymen, and the work which he wished to inaugurate, were a beginning of that grander but not more creditable work effected by the Morrill Land Grant Act, and resulted undoubtedly in greatly stimulating such foundations as that of the Pratt Institute many years later, and many other less extensive but no less well-meant enterprises of the same kind which now are becoming not uncommon in the various larger cities of the United States.

The Stevens Institute of Technology was founded in 1870 and opened for students in 1871, as a school of mechanical engineering solely, although it has, at times, admitted students to study in departments of pure science and has conferred upon such the degrees of B.S. and Ph.D., in a very few instances; the latter being usually an honorary title, however. Its founder was Edwin A. Stevens, the son, and the sole surviving heir at the time, of

the famous Colonel John Stevens, who, at the beginning of the century, inaugurated the applications of steam to the railway and to navigation in this country, after the way had been "blazed" by Fitch, Fulton, Bell, Trevithick, and Stevenson. John Stevens was the principal mover in the organization of the steamboat lines on the Delaware and the Connecticut, and later, after the downfall of the Livingston and Fulton monopoly, on the Hudson. He was a prime mover in the construction of the Camden and Amboy Railway, and published, long before that even, a pamphlet (1812) in which he presented his views and arguments showing the feasibility of the use of steam on railways and their superiority, as a system of general transportation throughout a broad country like ours, to the canals which were at the time proposed by De Witt Clinton and others. He was "undoubtedly the greatest engineer and naval architect living at the beginning of the present century. Without having made any one superlatively great improvement in the mechanism of the steam-engine like that which gave Watt his fame; without having the honor of being the first to propose navigation by steam, or steam transportation on land, he exhibited a far better knowledge of the science and of the art of engineering than any man of his time. He entertained and urged more advanced views of and more statesman-like opinions in relation to the economical importance of the improvement of the steam-engine, both on land and water, than seem to have been attributable to any other leading engineer of that time."

John Stevens built a number of steamboats at about the beginning of the century, among which were boats with screws and boats driven by paddle wheels, their engines constructed with and without condensers. He employed twin screws and high-pressure steam as early as 1805, and engine, boiler, and screws are still preserved, relics of the most remarkable work of the time.* He designed an iron-clad in 1812, intended to turn on an axis, discharging its guns as they came into line of fire, much as the Timby turret was intended to work (1844).

His sons were Robert L., James C., and Edwin A. Stevens. They aided their father in his great enterprises, inheriting his talents and professional skill and knowledge, and added enormously to the already large fortune accumulated by the father. Robert L. Stevens, especially, was a genius in his field. He in-

* "The Stevens of Hoboken: Engineers, Naval Architects, and Philanthropists." R. H. Thurston, *Jour. Frank. Inst.*, 1874.

vented many ingenious and valuable improvements in engineering construction, and is the originator of the hollow water line for vessels, commonly attributed to John Scott Russell. He gave form to the peculiar "Hudson River steamboat," and its singularly successful "beam engine;" used anthracite coal and a fan blower to intensify the draught; made the balanced "poppet" valve; invented the "Stevens cut-off," in conjunction with another genius, his nephew Mr. Francis B. Stevens; and improved the construction of locomotives and of ordnance, using a percussion shell in the latter and shot fitted with wings to insure rotation when fired from the smooth-bored guns of the period. The three brothers united in construction for the United States Government (1837–1854) an iron-clad 415 feet long, 45 feet beam, 5,000 tons displacement, to carry armor $6\frac{3}{4}$ inches thick, and to have a speed of twenty miles an hour. The engines were over 8,500 H.P., driving twin screws, and the ship had the graceful lines of a modern transatlantic "racer," and the proportions of length to breadth and depth adopted were precisely those of some of the most successful of contemporary ships. Owing, however, to the delays and never-constant policy of the successive adminstrations of the Government, this ship was never finished. Mr. Edwin A. Stevens was the surviving member of this remarkable family, and in his life he endeavored to complete the work of the brothers, and at his death he left a million of dollars for the purpose, but without avail.

In the same document by which he sought to continue and complete that work, he inaugurated a vastly more important and, in the end, remarkably successful enterprise: founding the Stevens Institute of Technology. For this purpose he bequeathed a half-million dollars as an endowment fund, gave $150,000 as a building fund, and a city square in Hoboken, adjacent to his own grounds, on which to erect its structures. He also conveyed to the city another square, directly in front of this last, which should be kept open as a public square, by the city, forever, thus insuring a pleasant and healthful location for the new institution. The stipulation was simply that an "institution of learning" should be organized, "for the benefit of the youth of New Jersey;" and no intimation was given as to its precise character or curriculum. The trustees, who were the executors of the will, at once appointed as its president Henry Morton, then of Philadelphia and at the time editor of the *Journal of the Franklin Institute*, and at his suggestion made the new school one of mechanical engineering purely,

with the avowed intention of restricting themselves to a single line of as yet undeveloped educational work, and of doing that one thing well. This plan has been steadily adhered to, and the school is, to-day, a school of mechanical engineering, giving a very elevated course of instruction, theoretically and practically, and graduating classes of about forty each year, among whom, during the twenty years of its existence, have been many of the most active and productive workers in the profession, and among whose recorded works are catalogued some of the most important investigations in this field on record. The researches of its faculty have always been in important lines and singularly fruitful.

The institution is prepared to do still more and better work, but is hampered by a lack of funds which prevents its receiving a larger number of students or erecting the buildings needed for its present purposes. It has never received outside aid, although long ago at its limit, except a few thousand dollars from a single bequest, and something like $50,000 from its president and alumni, mainly from the former, which gifts have been devoted to special purposes and to meet pressing needs.

The organization of this school as a special school of a single division of the field of engineering, and its success, had some influence, undoubtedly, in bringing other schools to a similar status. The Rensselaer Polytechnic School at Troy, N. Y., became a school of civil engineering purely; the Engineering Department of the School of Mines of Columbia College also restricted itself to other branches, allowing its neighbor, across the Hudson River, to take its special department without competition. Still other institutions have become, whether voluntarily or otherwise, schools, principally, of some one special branch, in which they have become known as peculiarly successful. Few schools, colleges, or universities even, in this country, to-day, are equally successful in all branches of technical work.

The trustees of the Stevens Institute very promptly yielded to an urgent demand, and authorized the writer, then the professor of engineering in that institution, in 1873, to establish a "mechanical laboratory" in conjunction with their engineering department. It is believed to be the first well-equipped "testing laboratory" organized in our country, and it quickly demonstrated the great value of reliable scientific facilities for technical research. The departments of physics, engineering, chemistry, drawing, etc., are so amply furnished with needful appliances as to afford unrivalled

opportunity to facilitate investigating operations. The institute, too, has been equally fortunate in the possession of proficient and well-trained experimenters. Our National Government, railroad and other corporations, together with business men representing mechanical and the various other industries, gladly avail themselves of the superior advantages of our college laboratories for impartial experimental investigations bearing upon important public and private interests.

THE TECHNICAL SCHOOLS OF CORNELL UNIVERSITY constitute the system of schools inaugurated for the special work assigned the university as the Land Grant College of the State of New York. They consist of the schools or colleges of Civil and Mechanical Engineering and of Architecture.

FUNDS RECEIVED, 1885–1892.

Increase of income-bearing funds	
Sales of land and timber (partly est.)	$1,229,580
Susan Linn Sage Fund, for School of Philosophy	250,000
Sage Library Endowment Fund	300,000
Fayerweather Fund	200,000
Four other small funds	6,532
Total increase of income funds	$1,986,112
Increase in buildings and equipment :	
From A. S. Barnes for Barnes Hall	45,000
" H. W. Sage for library building	260,000
" H. W. Sage, two other gifts	19,216
" President White, library	100,000
" Hiram Sibley, for mech. laboratory	16,000
" other persons for apparatus, etc	25,000
Total increase in buildings and equipment	$465,216
Additions from current income :	
Sundry buildings	$384,081
Library, museum, and laboratories	205,217
Sewerage, water-works, and vaults	69,664
Surplus fund (partly est.)	47,747
Total increase from current income	$706,709
Total from sales of land endowment	1,229,580
Total from further gifts	1,221,748
Grand total of 7 years' gain of funds	$3,158,037

The above table is given by President Adams, in his report of 1892, as exhibiting the receipts of the university from other

sources than the original endowments of the United States and of Ezra Cornell, during the period of his administration, and gives some idea of the manner in which the establishment of such institutions in the United States has awakened private interest and induced individuals to assist in the promotion of the plans thus set in operation for the education of the industrial classes. The income-bearing investments already in possession of the university, mainly the Cornell Endowment Fund, amounted, in 1885, to not far from $4,000,000.

The Cornell Fund, held apart from the Government Land Grant Fund, is not subject to the restrictions of the law of 1862, and may, at the discretion of the trustees, be appropriated to the erection and maintenance of buildings, or such other purposes as they may find needful. Mr. Cornell's own declaration was made in the now famous saying, "I would found an institution where any person may find instruction in any study," and he hoped that the time would come, as he sometimes said to his friends, when a great university should cover his homestead farm with its buildings and thousands of students swarm in its halls. His own personal interests were mainly in the promotion of the purposes of the Morrill Bill, and his aid was mainly intended to promote the interests of the "industrial classes." He was deeply interested in the establishment, especially, of workshops in which young men should be given instruction in the use of tools and taught trades, and, if possible, at the same time, given the opportunity of earning their own living while attending the university. This last plan did not succeed, and Cornell's manual training and trade schools have risen far above the level then assigned them, and have become schools of engineering. Whether this elevation of grade is an advantage to the State or to the nation may be an open question; but the facts above stated constitute the history of the inauguration and growth of the technical schools of Cornell University. The rate and the extent of that growth during the first dozen years of the work of the university are shown in the next table, which shows that the "leading purposes" of the institution were not at first accomplished to any visible extent; while the older education, which by the Land Grant Act the university was founded to supplement, not to carry on, as its own peculiar work, became, for a time, the principal work of the institution. In 1871 graduates in civil engineering began to appear on the commencement stage, and in 1873 the other technical

GRADUATES OF CORNELL UNIVERSITY, 1869–81.

	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881
Civil engineering	....	....	7	16	18	15	8	12	15	14	10	7	9
Mechanical engineering	....	....	...	....	3	1	5	6	7	12	5	3	3
Architecture	....	....	....	....	1	6	4	6	4	2	6	2	...
Agriculture	....	....	....	...	2	2	1	1	2	1	....	3	3
Total technical	....	....	7	16	24	24	18	25	31	29	20	15	20
Science	....	8	16	38	45	30	21	26	24	24	33	40	35
Total scientific	....	8	23	54	69	54	39	51	55	53	53	55	55
Letters	8	8	7	4	20	8	8	9	7	12	14	17	23
Philosophy	....	7	9	9	6	3	5	3	8	2	....	4	4
Total non-scientific	8	15	16	13	26	11	13	12	15	14	14	21	27
Grand total	8	23	39	67	95	65	52	63	70	67	67	76	82
Post-graduate degrees :													
Scientific	....	....	....	1	1	7	3	6	5	2	3	....	3
Non-scientific	....	....	....	1	2	1	....	4	3	1	1	....	....

courses commenced turning out their classes. The numbers were small throughout the whole of this first period, and the "leading purpose" of Cornell University was not to any great extent carried out until within the last few years. This is the fact with all of the so-called Land Grant Colleges, where comprising the old classical and the new non-classical curricula in their work.

GRADUATES OF CORNELL UNIVERSITY, 1886–92.

Engineering Courses.	1886	1887	1888	1889	1890	1891	1892
Civil engineering	10	17	21	14	15	24	32
Mechanical engineering, regular	5	12	14	13	26	24	44
Mechanical engineering, electrical	5	7	8	19	28	28	46
Mechanical engineering, total	10	19	22	32	54	52	90
Architecture	6	4	11	6	19	8	6
Agriculture	1	...	7	6	7	11	8
Total technical	27	40	61	58	95	95	136
Science	2	8	9	13	18	16	24
Chemistry and pharmacy	....	1	2	2	4	3	...
Natural history	4	....	....	....	....	....	....
Total scientific	33	49	72	73	117	114	160
Law	...	....	9	36	32	44	41
Literature, letters	1	17	27	19	39	31	33
Arts and philosophy	48	35	29	29	33	40	61
Total non-scientific	79	52	65	84	104	115	135
Grand total	82	91	137	157	221	229	295
Post graduate degrees :							
Scientific	7	3	6	7	14	12	29
Non-scientific	4	1	6	2	10	9	18

The "leading object" of the law and their charters has usually been but slightly productive, while the older education and other than the industrial classes have largely profited by the endowments specially assigned the latter. This is probably largely due to the fact that it has rarely happened that the management of these institutions has fallen into the hands of educators in full sympathy with the purpose of the foundation, or of those who have either an understanding of the requirements in that later line of educational work or of the methods of meeting them. With presidents and boards of trustees familiar with, and interested in, the work laid out by the Morrill Act, it may be fairly presumed that the results of its operation would have proved even vastly more advantageous than it actually has. But it must be remembered that when these colleges were set in operation under that act, and under the legislation of the several States which founded them, the only educators professionally engaged as such were men who had been educated in the old, and usually exclusively in the classical, courses, and who had had no experience in the new, no knowledge, and no precedents. They also seldom had much sympathy with the movement, and, in many cases, obstructed rather than promoted the objects which it was their duty, in all ways, to seek to attain. The wonder, under the circumstances, is that so much should have been actually accomplished.

It is more than possible that a counterbalancing advantage accruing from this majority control of our schools of engineering, in so many—in most—cases, by non-professionals, has been the placing of a brake upon the disposition sometimes manifest to depreciate culture and to seek to substitute business training for it.

The preceding statistics show, among other interesting facts, the result of what is perhaps the most definite and purposeful endeavor yet made to make an engineering school a purely professional institution—such as are, for example, all the great law schools—instead of, as is customary, attempting to give a mixed course of educational and of professional instruction. At the beginning of the period covered by the last table, the usual curriculum was offered, including a little rhetoric, a little literature, and a little of sundry other matters, filling up with professional work of a necessarily very elementary kind. It was found impracticable to give either enough of the non-professional work

to constitute an education, or sufficient of the professional work to carry the student up into the departments of research or real professional work in applied science. Neither kind of work was done well or in satisfactory amount; and the school was neither educational nor professional. In later years, it has been gradually brought into a more satisfactory shape by the elimination of all the elementary educational studies, replacing them by higher professional work; meantime compelling the student to enter with a good scientific preparation, especially with the higher mathematics, and always advising that he get so much of a real education as his time and his means permit before entering the professional school; that he do one of the two things at a time and do that one thing well, giving his whole time, strength, and thought to the matter in hand at the time. Under this arrangement, the college has continually received larger and larger classes, and students of continually improving quality in both age and maturity and in preparation. Men graduating from the present course are far better-educated men, as a rule, as well as better men professionally, than when it was the practice to offer a mixed educational and professional course. Both the educational and the professional training are, on the whole and usually, better done, it is thought, as the result of this experience, when the motto is made, "This one thing I do."

Cornell University is the State university of the "Empire State," yet nothing, practically, has yet been done by the State for its greatest institution of learning. All that has been done, thus far, has been accomplished through the energy, benevolence, and wisdom of private citizens. What may be accomplished in this manner is here an object-lesson to the world; but what may be accomplished when, at some future time, that State shall do its part in this the greatest work which falls to it to perform, can only be faintly imagined from what has been already accomplished without that aid and under a thousand disadvantages and difficulties that the State only can evade or remove, and under unimaginable obstructive conditions that the hearty and helpful assistance of the State in the past might have converted into enormously productive aids to advancement.

PRIVATE ENDOWMENTS of magnitude, in the United States, have not been numerous, notwithstanding the fact that the aggregate of such endowments is very great and constitutes the support of substantially all of the older colleges and universities of the

country. The foundation of the Stevens Institute of Technology among technical schools, of the Johns Hopkins University among colleges and universities, illustrate the case of complete endowments by single individuals; and the Massachusetts Institute of Technology is another example of private endowment, mainly secured by the coöperation of numbers. The first and the last named of these institutions are elsewhere spoken of. The Johns Hopkins University, although not classed as a technical school or as having technical work introduced into its scheme to a larger extent than the older colleges, nevertheless deserves mention as being, among American colleges giving mainly the classical courses—the "culture courses" of the older systems—the first to introduce the extensive study of science, and especially of the most elevated work in pure science, together with a large amount of the most fruitful work in research and applied science. It has from the first maintained a strong faculty in natural science, and has done the best of work in that field. It has been especially strong in mathematics and the physical sciences; and the work of Sylvester and others in mathematics, of Rowland and his colleagues in physics, and of Remsen in chemistry, have made that university known the world over. There has never, in any land, been a larger work done in research and in publication in these fields than at the Johns Hopkins University. The standard maintained and the character of its work are indicated by the fact that its students are very largely graduates, and that their work includes a large amount of research. The university has, of late years, developed a department of applied physics, and especially of electrical physics, which has accomplished a large amount of excellent work in the training of students to enter upon that line of engineering practice. This has perhaps been its most extensive and productive technical department of instruction.

As illustrating the form given private endowments of the class here especially considered, reference may be made to the Miller Manual Labor School of Virginia, and the Chicago Manual Training School, in the lower, and to the Leland Stanford, Jr., University in the higher, fields of educational work. The first named was founded upon a bequest of Samuel Miller, a native Virginian, who died at his place, near Lynchburg, Va., in 1869. The endowment was in good securities having a value of about $1,500,000, and yielding an income of about $75,000 per annum. The school is at a pleasant spot in Albemarle County, near the

post-office town of Crozet, Va., and is educating poor orphan children. It is managed by two gentlemen annually appointed by the County Court of Albemarle, and a faculty selected and directed by these appointees. It has educated from 33 to about 300 pupils, annually, from its opening in 1878. It is a technical and manual-training school, has an excellent outfit in buildings and equipment, and follows as nearly as is practicable the methods of the Worcester Polytechnic Institute. The cost of its entire plant is about $350,000. All pupils accepted are fed, clothed, and cared for as in a home. Their parents or guardians are compelled to surrender to the school authorities all legal control during their residence at the school. As a rule, they are not retained as pupils after passing the age of eighteen. The work of the school is thus unique and has proved most successful.

The Chicago Manual Training School, like the Massachusetts Institute of Technology, owes its establishment to the enlightened sentiment of the citizens of the place, guided and given practical effect by the active aid and pecuniary support of a few wealthy men in the community. It was founded by the Commercial Club through the legal action of its "Chicago Manual Training School Association," incorporated April 19, 1883. Its work began in February, 1884, and its first class was graduated in June, 1886. It is a high school in which is incorporated a manual-training school of very high class. Under the direction of Dr. Belfield, it has gained rapidly in position, reputation, and numbers of students, and its certificates of graduation are now accepted for entrance into the universities of Michigan and Illinois, the Cornell University, and other institutions having the more advanced engineering courses in operation. The school now has about 350 students. The new Armour School of Chicago will have a somewhat similar character; its organization is now complete, and a great work is expected of that new recruit in the educational army.

The Pratt Institute of Brooklyn is still another of these technical high schools, and has a still broader field than either of the preceding. It was founded in 1887 by Mr. Charles Pratt, of Brooklyn, as a technical high school in which he proposed to give instruction in all the usual branches of high school work and also in as many lines of manual training and trade instruction as might prove practicable. It is managed by a faculty of considerable size, under the general direction of Mr. Pratt's sons, as

trustees, and with the aid of Mr. F. B. Pratt, acting as its secretary and as chairman of the faculty. The school not only teaches regular courses for the benefit of day scholars and regular students, but also night classes for the benefit of young men and women who work in the daytime and can only attend in the evening. The endowments, in October, 1891, amounted to $2,000,000, and its inventory of property to over $1,500,000 more, including above $330,000 in rented dwellings of model construction. Its income is about $100,000 per annum.

Its registration has already amounted to about 2,000 day scholars, and nearly as many evening pupils. It has about 75 instructors, and the roll of visitors for the year amounts to above 10,000 persons. Its courses of instruction include those of the Art Department; of the Department of Domestic Science, in which are given courses of instruction in every branch of house economy; a Commercial Department, a Department of Mechanic Arts, and one of Music. Its library contains an extensive and well-selected collection of books in all the departments of literature, and the issues for the year amount to about 150,000. It would be difficult to find or to conceive a more profitable application of funds than is here illustrated, and the growth of the work is steadily progressing.

The Leland Stanford, Jr. University stands at the opposite extreme of the line of technical institutions. It was founded under the general laws of California, by Mr. and Mrs. Leland Stanford, as a memorial to their son, who died at the age at which youth and manhood meet, leaving them childless. Its purpose is that of the Land Grant Colleges founded by the Federal Government, but its whole endowment is given by Mr. Stanford, and it is entirely independent of public support. Its control remained in the hands of the founder, and of his widow, who now survives; but after their death it is vested in a board of trustees. The institution is co-educational, and is intended to include the older with the so-called "new" education, "with the colleges, schools, seminaries of learning, mechanics' institutes, museums, galleries of art, and all other things necessary and appropriate to a university of high degree." The university is endowed with about 85,000 acres of the most productive and valuable land in California, largely under cultivation and likely in the future to prove enormously valuable. The location of the college is at Palo Alto, about an hour's ride from San Francisco. It has a large body of students,

numbering already several hundred, and including an exceptional proportion of graduates engaged in advanced work. The technical departments are well organized, and civil and mechanical engineering and architecture promise to find splendid representation here in time, notwithstanding the proximity and rivalry of the State Land Grant University at Berkeley, across the bay from San Francisco and but forty miles away from Palo Alto. It is estimated that its endowments may, in time, attain the unprecedented magnitude of twenty million dollars. It has already a large number of fine and costly buildings, and is expending something like a half-million dollars a year on its work and extensions, under the direct supervision of President Jordan. In the course of events it would seem probable that it must follow the tendency of the age, and, even if not so specifically directed by its trustees, will become more and more technical in its character, ministering continually more and more to the primary needs of the people. The indications thus are that it may some time become a great technical university, such as John Scott Russell contemplated in his scheme of a system of education of the nation.

The Rose Polytechnic School at Terre Haute, Indiana, the Case School at Cleveland, Ohio, and others of their class, independent engineering schools, endowed, often, with large sums and having incomes making them more or less independent of tuition fees, are rising all over the land to contribute their share in the great work of offering to the "industrial classes" and to aspirants to entrance into these professions a scientific and sound education in the fundamental principles upon which the work of the professions must be made to rest. They are at once great public institutions for the promotion of the best interests of the people, and monuments to a philanthropy and benevolence which is becoming constantly more general among the wealthy citizens of the country, and as constantly more discriminating in application.

THE MAGNITUDE OF THE WORK OF TECHNICAL EDUCATION in the United States is greater than is usually supposed, notwithstanding the fact that it is so absolutely inadequate to the needs and opportunities of our country. The best authority of recent date, *Engineering News*, makes the total number of schools properly and regularly conferring degrees in engineering 94, while the number reported as conferring diplomas in science, among which are many doing some real professional work, outside the list of 94, is

about 240. Of the larger list, 216 are found to have conferred 1,616 degrees in science and engineering in 1889, of which 993 were given by 75 colleges and professional schools recognized as entitled to rank with engineering schools of the professional type. The average number graduating from the engineering schools and colleges was 13.5, and from the other class 4.5, showing clearly the tendency of the professional and so-called "practical" education to attract the American youth, and the inclination of the latter to desert the schools giving that purely gymnastic education which was, until lately, the only recognized culture. It should, however, be remarked that the tendency to combine both lines of work by taking first the established academic courses, then entering the technical school, is beginning to become manifest, and, at least in the writer's experience, with a somewhat rapid development and a most gratifying excellence of result.

The 94 schools in the first list are not all engineering schools in the sense of being wholly or even mainly professional schools; but all offer engineering courses and tender diplomas in engineering.

The following is a summary of the contributions made to the cause of "education of the people, by the people, for the people" from the earlier days of the Republic: *

(1) Lands by the township, under acts of 1787 and 1800, amounting to over one million acres, for the support of State universities.

(2) A considerable but unascertained proportion of the money surplus of twenty-eight million dollars distributed to the States in 1836 and never recalled.

(3) A portion of the three and a half million dollars constituting the share of education in the total proceeds of land sales under the percentage acts of 1841 and later.

(4) A portion of the three and a half million acres accorded by different States to education out of the nine and a half million acres given by Congress in 1841 for internal improvements.

(5) Further important sums not definitely known, from the sale of over fifty million acres of swamp lands disposed of under provisions of the act of 1850, from which source alone the University of California is said to have derived important aid.

(6) Revenues in a number of States from the sale of saline

* Blackmar's Report, of 1890, to the Bureau of Education. Hoyt's Report, of 1892, to the Senate Committee on a National University.

lands, with appropriations thereof to the support of colleges of agriculture and the mechanic arts.

(7) The more than $15,000,000 already derived from the lands accorded to States by the act of July 2, 1862, for the support of colleges and the mechanic arts; which grant has resulted not only in the establishment of many important technical institutions, but also at the same time in such strengthening of the State universities that some of them are thus early taking their places in the foreground of the great university field.

(8) The appropriation by act of March 2, 1887, of $15,000 per annum to each State for experimental purposes in aid of scientific agriculture in the broadest sense of that term, a yet further incidental reënforcement of the many State universities.*

(9) The aggregate of over $20,000,000 appropriated for the support of the Military Academy at West Point and the Naval Academy at Annapolis.

(10) The establishment, equipment, and support of the Naval Observatory and the purely scientific bureaus of the Government at Washington.

(11) The large sums of money appropriated for the convenience and support of the Congressional and departmental libraries.

(12) The hundreds of thousands expended in buildings for the scientific museums of the Government, and the more than $3,000,000 a year so wisely granted for their support.

The following is the list of these schools, as above, together with the numbers of graduates reported for the last year given, as collated and published by our authority in this matter: †

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* The State of New York, as stated in the message of the governor for 1892–3, taught in the public schools 1,073,093 children in the year 1892, and 772,426 were either educated in private schools or were not taught at all. The State expended in this work $21,134,516; which was $865,000 more than was paid out, on the same account, in 1891.

† *Engineering News*, March 26, 1892.

ENGINEERING SCHOOLS OF THE UNITED STATES.

Names having numbers prefixed are schools of recognized standing.

Names having (*a*) prefixed are not strictly engineering schools, though working in that direction.

Names having (*b*) prefixed are too recently established to have their character determined.

Names having (*c*) prefixed have no separate and distinct engineering courses.

Names having (*d*) prefixed furnished scant information.

Names having (*e*) prefixed sent catalogues only.

Names having (*f*) prefixed sent no information.

Name of College.	Location.	No. Grads. '89.
20 Maine Agricultural College	Orono	6
(*b*) New Hampshire Agricultural College	Hanover	6
23½ Dartmouth (Sci. Dept.)	Hanover	2
3 Mass., Harvard University (Sci. Dept.)	Cambridge	0
10 Mass. Institute of Technology	Boston	60
13 Tufts College (Sci. Dept. of)	College Hill	4
18 Worcester Polytechnic School	Worcester	27
(*f*) Mass. Agricultural College	Worcester	14
(*d*) Vermont, University of (Sci. Dept.)	Burlington	3
(*c*) Rhode Island, Brown University	Providence	0
2 Conn., Yale University (Sci. Dept.)	New Haven	39
Total, New England States, 11 schools		161
1 N. Y., Rensselaer Polytechnic Institute	Troy	18
4 N. Y., Union College (Sci. Dept.)	Schenectady	4
6 N. Y., Brooklyn Polytechnic Institute	Brooklyn	7
8 N. Y., Columbia College (Sci. Dept.)	New York	29
12 N. Y., Cornell University (E. Dept.)	Ithaca	14
24½ N. Y., Cornell University (M. E. Dept.)	Ithaca	33
(*d*) N. Y., University of City of New York (Sci Dept.)	New York	13
(*e*) N. Y., Syracuse University	Syracuse	6
22½ N. J., Stevens Institute	Hoboken	36
27 N. J., Rutgers College (Sci. Dept.)	New Brunswick	14
(*e*) N. J., College of New Jersey	Princeton	..
7 Penn. Military Academy	Chester	11
22 Penn., University of Pennsylvania (Sci. Dept.)	Philadelphia	9
24 Penn., Swarthmore College (Sci. Dept.)	Swarthmore	6
10½ Penn., Lehigh University (Sci. Dept.)	Bethlehem	31
15 Penn., Lafayette College (Sci. Dept.)	Easton	4
(*b*) Penn., University of Western Pa. (Sci. Dept.)	Allegheny	1
(*c*) Penn., Haverford College (Sci. Dept.)	Haverford College	7
(*e*) Penn., Pennsylvania Military Academy	Chester	11
(*b*) Del., Delaware College (Sci. Dept.)	Newark	1
Total, Middle States, 20 schools		255

	Name of College.	Location.	No. Grads. '89.
(e)	D. C., Columbian University (Sci. Dept.)	Washington	0
(f)	Md. Agricultural College (M. E. Dept.)	Agricultural College.	4
(e)	Md., St. John's College (Sci. Dept.)	Annapolis	4
9	Va., Washington and Lee University (Sci. Dept.)	Lexington	1
11	Va., University of (Sci. Dept.)	Charlotteville	5
(c)	Va. Military Institute	Lexington	5
(e)	Va. Agricultural and Mech. College (M. E. Dept.)	Blacksburg	3
(b)	W. Va., University of (Sci. Dept.)	Morganstown	6
(b)	N. C., Trinity College (Sci. Dept.)	Trinity College	0
(b)	N. C., College of Agr. and Mech. Arts (M. E. Dept.)	Mt. Pleasant	0
(e)	N. C., University of (Sci. Dept.)	Chapel Hill	1
(a)	S. C., University of (Sci. Dept.)	Columbia	9
14	Ga., University of (Sci. Dept.)	Athens	4
42	Ga., School of Technology	Atlanta	2
(a)	Ga., Gainesville College (Sci. Dept.)	Gainesville	..
(c)	Fla., Agricultural College (M. E. Dept.)	Lake City	2
19	Ala., Polytechnic Institute	Auburn	6
(e)	Ala., University of (Sci. Dept.)	University	2
(f)	Miss., Alcorn Agricultural and Mechanical College		9
(a)	Miss., Agricultural College (M. E. Dept.)	Agricultural College	19
31	Texas Agricultural College (M. E. Dept.)	College Station	..
37	Texas, University of (Sci. Dept.)	Austin	2
(a)	Texas, Austin College (Sci. Dept.)	Sherman	..
(b)	Tenn., University of the South (Sci. Dept.)	Suwanee	2
(c)	Tenn., University of (Sci. Dept.)	Knoxville	..
(e)	Tenn., Vanderbilt University (Sci. Dept.)	Nashville	10
(a)	Kentucky, State College of		..
(f)	Kentucky Agricultural and Mechanical College (M. E. Dept.)		4
	Total, Southern States, 28 schools		100
(b)	Ohio, Case School of Applied Science	Cleveland	6
(d)	Ohio, University of Cincinnati (Sci. Dept.)	Cincinnati	7
(e)	Ohio, State University (Sci. Dept.)	Columbus	15
35	Ind., Purdue University (Sci. Dept.)	Lafayette	13
36	Ind., Rose Polytechnic Institute	Terre Haute	8
(a)	Ind., Wabash College (Sci. Dept.)	Crawfordsville	..
30	Illinois, University of (Sci. Dept.)	Champaign	4
5	Michigan, University of (Sci. Dept.)	Ann Arbor	19
39	Michigan Mining School	Houghton	6
40	Michigan Agricultural College (M. E. Dept.)	Agricultural College	6
23	Wisconsin, University of (Sci. Dept.)	Madison	9
26	Minnesota, University of (Sci. Dept.)	Minneapolis	3
28	Iowa, University of (Sci. Dept.)	Iowa City	2
29	Iowa, Cornell College (Sci. Dept.)	Mt. Vernon	8
21	Iowa Agricultural College (M. E. Dept.)	Ames	7
16	Mo., Washington University (Sci. Dept.)	St. Louis	3
(d)	Missouri School of Mines	Rolla	15
(e)	Missouri State University (Sci. Dept.)	Columbia	16

	Name of College.	Location.	No. Grads. '89.
17	Kansas Agricultural College (M. E. Dept.)	Manhattan	17
25	Kansas, University of (Sci. Dept.)	Lawrence	3
(*a*)	Kan., Campbell University (Sci. Dept.)	Holton	..
(*a*)	Kan., Ottawa University (Sci. Dept.)	Ottawa	..
32	Nebraska, University of (Sci. Dept.)	Lincoln	3
(*a*)	North Dakota, University of (Sci. Dept.)	Grand Forks	3
(*a*)	South Dakota, Agricultural Coll. of (M. E. Dept.)	Brookings	3
(*b*)	South Dakota, Pierre University (Sci. Dept.)	Pierre	0
33	Colorado School of Mines	Golden	4
(*e*)	Colorado State Agricultural College (M. E. Dept.)	Ft. Collins	4
(*b*)	Montana School of Mines	Deer Lodge	0
	Total, North Central States, 29 schools		184
(*b*)	Oregon State Agricultural College (M. E. Dept.)	Corvallis	13
(*b*)	Cal., Pierce Christian College (Sci. Dept.)		0
(*d*)	California, University of (Sci. Dept.)	Berkeley	11
(*e*)	Nevada State University (Sci. Dept.)		0
(*b*)	New Mexico Agricultural College (M. E. Dept.)		0
(*a*)	Utah, Agricultural College		..
	Total, Pacific States, 6 Schools		24

TOTAL NUMBER OF GRADUATES, 1889.

(As reported to the Bureau of Education, with some corrections.)

	In listed Schools.	In schools marked						Total.
		(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	
New England	138	..	6	..	3	..	14	161
Middle	216	..	2	..	13	24	.	255
Southern	20	28	8	5	..	22	17	100
North Central	115	6	6	..	22	35	..	184
Pacific	....	..	13	..	11	..	..	24
Total	489	34	35	5	49	81	31	724

The following is the list of institutions which are classed among those doing work in science, but not as properly coming into the preceding classification either as being or as including professional schools in engineering: *

* *Engineering News*, March 19, 1892.

COLLEGES CONFERRING DEGREES IN SCIENCE.

Total number, 141.

	Graduates in science, 1889.
Vermont. Middlebury College	2
Norwich University	7
Massachusetts. Agricultural College	14
Connecticut. Wesleyan University	3
Storrs Agricultural College	0
New York. St. Lawrence University	9
Hobart College	5
Manhattan College	5
College of City of New York (not the University of the City of New York)	26
University of Rochester	5
Pennsylvania. Lebanon Valley College	2
Dickinson College	2
Ursinus College	3
Pennsylvania College	4
Grove City College	15
Bucknell University	3
Allegheny College	1
Central Pennsylvania College	2
Westminster College	13
Pennsylvania State College	15
Villanova College	3
Washington and Jefferson College	1
Maryland. Agricultural College	4
District of Columbia. Deaf Mute College	2
North Carolina. Davidson College	1
Rutherford College	2
Wake Forest College	5
South Carolina. Erskine College	4
Furman University	1
Georgia. Mercer University	2
Emory College	2
North Georgia, Southwest Georgia, West Georgia, Middle Georgia — Agricultural and Mechanical College	0
Alabama. Southern University	3
Spring Hill College	7
Mississippi. University of Mississippi	6
Alcorn Agricultural & Mechanical College	9
Louisiana. State University and A. and M. College	6
Keachie College	1
Straight University	9
Tulare University of Louisiana	4
Tennessee. Grant Memorial University	8
King College	1

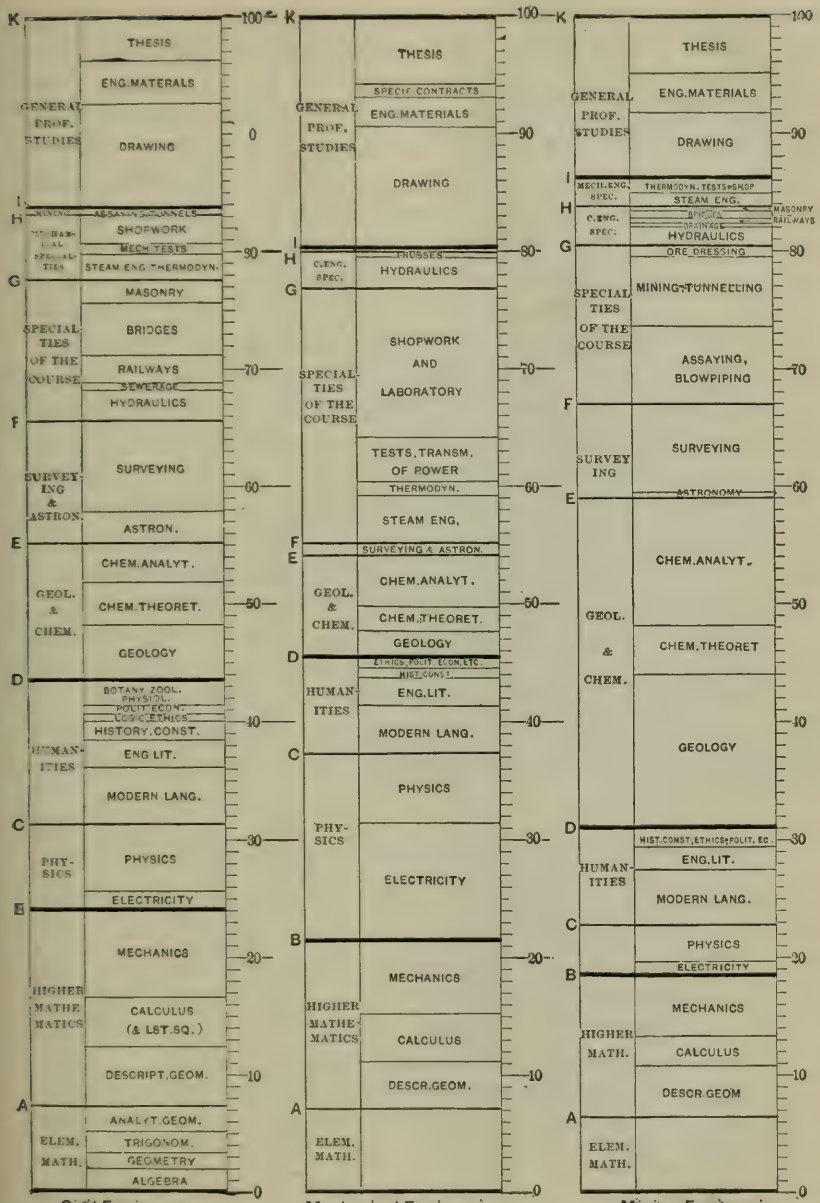
	Graduates in science, 1889.
Tennessee. Hiwassee College	1
Cumberland University	6
Bethel College	8
Milligan College	3
Kentucky. Berea College	1
Eminence College	2
Georgetown College	3
Central University	5
Bethel College	1
St. Mary's College	1
Agricultural and Mechanical College	4
Arkansas. College of Arkansas	1
Little Rock University	3
Philander Smith College	2
Texas. Fort Worth University	1
Southwestern University	11
Ohio. Ashland University	2
Buchtel College	4
Mt. Union College	6
German Wallace College	2
Culvin College	1
Ohio Wesleyan University	7
Denison University	6
Hiram College	2
Franklin College	1
Muskingum College	3
Heidelberg College	5
Wilberforce College	3
Wilmington College	2
Indiana. Franklin College	6
De Pauw University	10
Hanover College	9
Hartsville College	9
Butler University	3
Moore's Hill College	7
University of Notre Dame	5
Earlham College	6
Illinois. Wesleyan University	9
Eureka College	4
Northwestern University	5
Ewing College	1
Knox College	28
Lombard University	10
Illinois College	4
Lake Forest University	2
McKendre College	8
Northwestern College	4
Augustana College	2
Westfield College	2

	Graduates in science, 1889.
Illinois. Wheaton College	2
Michigan. Adrian College	4
Albion College	3
Hillsdale College	1
Kalamazoo College	1
Olivet College	6
Wisconsin. Lawrence University	6
Milton College	4
Racine College	2
Minnesota. Hamline College	7
Carlton College	2
Iowa. Cremourne College	1
Amity College	1
Parsons College	7
Upper Iowa University	2
Iowa College	4
Lenox College	6
Simpson College	3
Iowa Wesleyan University	3
Penn College	2
Central University of Iowa	1
Western College	4
Missouri. Avalon College	7
S. W. Baptist College	1
Christian University	2
Grand River College	10
Westminster College	9
Pritchett School Institute	4
Drury College	3
Tarkio College	5
Central Wesleyan College	2
Nebraska. Bellevue College	2
Doane College	2
Kansas. Baker University	6
Emporia College	1
South Dakota. Dakota University (Mitchell)	3
University of Dakota (Vermilion)	1
Yankton College	1
Montana. College of Montana	2
Colorado. University of Denver	6
California. University of the Pacific	11
St. Ignatius College	4
Santa Clara College	11
San Joaquin Valley College	3
Hesperian College	6
University of Southern California	0
Washington. University of Washington	1
Total	623

There is a striking contrast between the proportion of students taking graduate studies in the German universities and in those of France as compared with similar figures for the United States. While in France and Germany twenty-eight per cent. of the total registration is in this class, in the United States the proportion is but about seven per cent. Yet this is a gain of one thousand per cent. in twenty years, and some of the larger universities of the country now number their graduate students by hundreds.

The accompanying diagram, from the same source as the preceding, illustrates, better than can any verbal description, the usual distribution of studies among the engineering schools, in each of the three principal lines of work. All three courses are seen to have the same general character and succession of studies, beginning with elementary mathematics, including the higher branches of that department of instruction, giving large space to applied mechanics, considerable time to the physical sciences, still more to the characteristic work of the special course considered, always including a study of the materials of construction, of the strength of materials and modifying conditions, structure, and design and construction, of the subject of the branch taught, and concluding with a "graduating thesis," which is now very generally the description and discussion of an original design or of work in research in which the student engages during the closing period of his course. The diagram exhibits neither the best nor the worst of the courses taught; but as a mean of many—usually, however, leading—college courses, it represents the judgment of the average authority, tempered by that conservatism which invariably tends to act as a brake upon progress, and to make the contemporary course a less effective one than the best judgment of contemporary authority would otherwise produce; while, at the same time, the typical course illustrated is a better one than the less excellent and lower courses of the weaker colleges and schools. The diagram may be taken, perhaps, as representing the best courses of recent years, present practice differing mainly in the reduction of the time appropriated to elementary studies and extension of the special work of the course, resulting in a change toward the form of the graduate professional school, entrance to which should occur, although not necessarily or compulsorily, through general courses of study at non-professional schools and colleges.

The characteristic studies of the course in civil engineering, for



MEAN DISTRIBUTION OF TIME OF ENGINEERING COURSES.

Eng. by Am. Bank Note Co. N. Y.

Fig. 324.

example, are surveying, railway, canal, and bridge construction, and public works generally. The purpose of the elementary mathematics and of studies in science is simply to afford that scientific knowledge which is essential to success in these special subjects. As they can be more and more completely and satisfactorily supplied previous to entrance and in the preparatory schools, the engineering school tends to become more and more purely professional. Similarly, in the mechanical engineering course, the special subjects are machine design construction and operation and the test of the materials of which they are composed and of the completed machine; in mining, the special subjects of instruction are surveying, mining, the construction of mining apparatus and machinery, assay of ores; and these subjects continually assume more and more importance and occupy more and more entirely the time assigned the course. Like the older professional schools, the modern engineering school is constantly concentrating its work upon its special purpose, and calling upon the non-professional schools for its preparatory instruction.

The extent to which mechanical engineering has come forward as a profession, and as a learned profession, since its first establishment distinct from civil engineering by the schools, only twenty-five years ago, will be seen on examining the following table, extracted from the same series of papers to which we have been throughout this discussion indebted, which table was compiled for the year 1892.

GRADUATES OF PROFESSIONAL M. E. SCHOOLS, JUNE, 1892.

1	school (Sibley Coll., Cornell) had	79	graduates.*
1	" (Mass. Inst. Tech.) had	61	"
1	" (Yale, Sheffield S. S.) had	49	"
1	" (Stevens Inst. Tech.) had	39	"
1	" (Rose Polyt. Inst.) had	23	"
1	" (Worc. Polyt. Inst.) had	22	"
	Total of 6 schools (average, 45½ each)	273	"
	(Against only 150 graduates from the 6 largest C. E. schools.)		
2	had 20 graduates each	40	
1	had 19 graduates	19	
1	had 17 graduates	17	
	Total of 10 largest schools	349	
	(No other than these 10 schools had so many as 10 graduates.)		

*The reported number is less than the actual, which was 90 in 1892, and, including students taking second degrees, over 100 in 1893.

1 had 9 graduates	9
4 had 8 graduates	32
2 had 7 graduates	14
2 had 6 graduates	12
1 had 5 graduates	5
2 had 4 graduates	8
1 had 3 graduates	3
5 had 2 graduates	10
3 had 1 graduate	3
1 had 0 graduate	0
22 had (average, 4 each)	96

The accompanying table, from the same source as the last, gives the statistics of graduates in mechanical engineering in the United States for a period of a quarter of a century to date, beginning with the year 1868, when the Massachusetts Institute of Technology sent out its first class, the Sheffield Scientific School a single graduate, and the Troy Polytechnic a class, large for the time, of five members—seven young men that year entering upon their professional careers in this branch. In 1892 the total number is seen to be 445, and the number of colleges reported as graduating students in this course is over thirty, and their graduates in mechanical engineering averaging, for the last year reported 14, and ranging from 1 to 79 (Sibley College, Cornell University). Eight colleges graduate twenty or more, each. The subdivision of electrical engineering has come in within the ten years just closing and has rapidly grown to include, in the larger schools, about one-half of all taking the mechanical engineering work. In schools, as Sibley College, in which this branch is made a special feature, more than one-half of all students sometimes take it, either with a view of making it a specialty after graduation, or with the assumption that every mechanical engineer must, to-day, be somewhat familiar with the peculiar work of the electrician and of the electrical engineer. In other schools, as the Stevens Institute of Technology, in which no distinction is made, it is expected that all students will secure sufficient familiarity with this subject to prove themselves competent, later, to enter upon that line of special work.

NUMBER OF GRADUATES FROM COURSES OF MECHANICAL ENGINEEERING.

School.	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	School.
1. Rensselaer	5	5	8	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Rensselaer.
3. Yale	1	...	...	2	(4)	10	6	9	(9)	(7)	(7)	(7)	(9)	(9)	(9)	(9)	(12)	16	(20)	(18)	(21)	(20)	(29)	50	49	Yale.
6. Univ. of Michigan	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1	1	6	7	6	7	7	9	Univ. of Michigan.
Totals, Group A	6	5	8	6	4	10	6	9	9	7	7	7	9	9	9	10	12	17	21	24	28	26	36	57	58	
9. Columbia	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	6	Columbia.
11. Mass. Inst. Tech	1	2	2	2	1	2	4	6	9	6	2	8	....	5	5	7	6	8	33	25	42	40	45	49	61	Mass. Inst. Tech.
12. Lehigh	....	1	2	1	....	2	....	....	3	....	5	2	2	1	....	7	4	4	6	12	14	12	9	13	19	Lehigh.
13. Univ. of Virginia	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	Univ. of Virginia.
Totals, Group B	1	3	4	3	1	4	4	6	12	6	7	10	2	6	5	14	10	12	39	37	56	52	54	68	86	
15. Tufts	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	5	1	3	7	7	8	Tufts.
16. Univ. Georgia	....	....	....	....	....	1	2	1	....	1	....	....	....	....	....	1	....	1	1	1	1	...	1	....	1	Univ. Virginia.
18. Washington U	....	....	....	....	1	....	....	....	....	....	2	....	....	2	....	....	1	....	1	2	4	....	2	....	4	Washington U.
20. Kans. Agr. C	....	....	....	(4)	(2)	(1)	(4)	(1)	(4)	(6)	(3)	(6)	(5)	(6)	(6)	(8)	(12)	(10)	(14)	(14)	(15)	(17)	(18)	(26)	(20)	Kans. Agr. C.
21. Worces. Poly. Inst	....	....	....	6	4	10	9	11	4	11	9	12	11	12	17	14	14	17	18	17	21	23	18	20	22	Worces. Poly. Inst.
22. Ala. Poly. Inst	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	Ala. Poly. Inst.
23. Me. Agr. Coll	....	....	....	....	....	....	....	3	5	4	1	4	....	3	5	1	1	4	3	4	6	2	15	6	8	Me. Agr. Coll.
24. Iowa Agr. Coll	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6	8	Iowa Agr. Coll.
Totals, Group C	....	....	....	10	7	12	15	16	13	22	13	24	16	23	28	24	28	32	39	43	48	45	61	65	73	
25. Univ. of Penn	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8	3	Univ. of Penn.
26. Stevens Inst. Tech	....	....	....	....	....	1	3	9	16	9	22	15	6	16	12	19	40	36	32	30	38	36	39	45	39	Stevens Inst. Tech.
27. Univ. of Wisconsin	....	....	....	....	....	....	....	....	....	....	....	....	1	1	....	3	5	5	4	4	5	4	3	7	8	Univ. of Wisconsin.
30. Cornell (Sibley Coll.)	....	....	....	....	....	....	3	3	4	2	5	5	5	5	6	7	10	7	10	19	24	33	60	52	79	Cornell (Sibley Coll.).
32. Univ. of California	....	....	....	....	....	....	....	....	....	2	1	3	....	6	3	....	1	....	....	2	3	2	4	6	2	Univ. of California.
33. Univ. of Kansas	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	....	1	Univ. of Kansas.
34. Univ. of Minnesota	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1	....	1	....	1	2	....	3	3	6	Univ. of Minnesota.
35. Rutgers	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	2	Rutgers.
38. Univ. of Illinois	....	....	....	....	....	....	....	....	....	....	4	1	2	1	5	1	1	5	5	5	2	3	11	7	4	Univ. of Illinois.
39. Univ. of Cincinnati	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	(1)	Univ. of Cincinnati.
Totals, Group D	....	....	....	....	....	1	6	12	20	13	33	24	14	29	26	31	57	54	51	61	74	78	123	131	145	
41. Texas Agr. Coll	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	3	3	6	7	Texas Agr. Coll.
42. Univ. of Nebraska	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	1	2	2	Univ. of Nebraska.
44. W. Univ. of Pa	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	W. Univ. of Pa.
45. Pa. State Coll	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6	5	Pa. State Coll.
46. Purdue	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	5	1	5	6	4	8	17	Purdue.
47. Rose Poly. Institute	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	8	10	4	10	14	23	Rose Poly. Institute.
50. Mich. Agr. Coll	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	3	6	9	6	7	Mich. Agr. Coll.
51. Ga. Sch. of Tech	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	8	20	Ga. Sch. of Tech.
Totals, Group E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	20	9	23	20	29	50	83	
Grand totals	7	8	12	19	12	27	31	43	54	48	60	65	41	67	68	79	107	117	170	174	229	221	303	371	445	

A large part of this extraordinary growth of the electrical branch is a real and healthy extension of the list of specialized lines of engineering which is constantly growing longer as the work of the profession of engineering becomes more complex. No such extension in any branch of construction has been witnessed since the introduction of the modern steam-engine by Watt opened the whole world of contemporary manufacture to mechanical engineers. The introduction, to-day, of this new auxiliary of steam and water power has given a very similar impetus to all lines of power and energy transmission, and the peculiar fascination of the subject as a branch of applied physical science has contributed to increase its attractions for ambitious and talented young engineers. The field will probably furnish place for a large body of these young men; but it is perhaps likely that the flood of applicants for opportunity to work in it will prove, presently, to be far in excess of the real demand, and frequent disappointment will check the singularly rapid growth of this division of the modern engineering school. The immense equipment required, also, and its commensurate cost of purchase and of maintenance and operation, tends to restrict the instruction given in this department to a few wealthy or large schools, and thus, in some degree, also, to put a brake upon this rapid acceleration. At the moment, however, there is no visible sign of a falling off of this growth or of the numbers finding employment in the work of transmission and application of electrical energy and of construction of the required "plants."

This development seems to have been peculiarly rapid and steady in the United States. Not only are there, apparently, no such schools of electrical engineering in the countries of Europe as in this country, but the number entering and graduating in such courses of professional study and training is nowhere else as large or as influential in determining the progress of the introduction of these recent improvements in power and light distribution. In this country, the student is taught in engineering schools the art of construction, as an engineer; in foreign schools, he is usually given admirable opportunities to acquire a good knowledge of the various branches of applied physics as involved in this branch of engineering, but is given little or no instruction in the essential, fundamental principles and practice of construction. He is made a physicist, not an engineer. This error is committed, in some instances, in this country, but only in colleges in which there are no facilities for engineering instruction, or where the work is

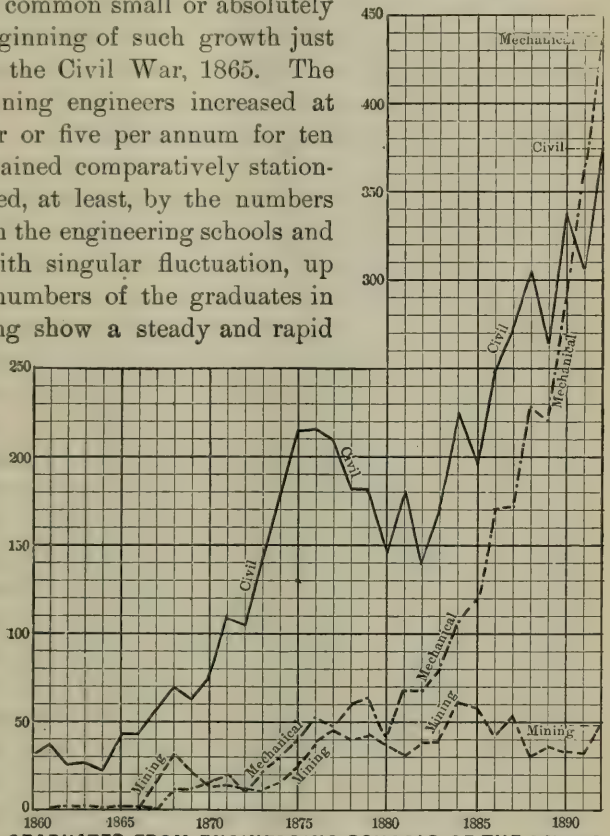
attempted to be performed by men of science rather than by practitioners in this branch of engineering. The engineer who is a physicist succeeds; the physicist who is an electrician but not an engineer must inevitably and invariably fail in all engineering work—and the work of the designer, builder, and operator of any and every kind of electrical machinery is mainly that of the engineer.*

The enormous rapidity with which the vocation of mechanical engineering, the occupation of the mechanic, has developed into a professional, or learned, vocation is strikingly illustrated by the graphical representation of the rate at which young men have, during the generation just past, been entering it through the colleges, and after a preparation often long, arduous, and exacting of both talent and industry, productive of a real culture and supplying a solid basis of learning of the most practically valuable sort. The plate herewith presented is reduced from a diagram made to exhibit the facts shown in the tables of figures already so largely quoted.†

* It is as essential that the engineer familiar with this branch of construction should plan and direct the courses of instruction in electrical engineering as that the student should be instructed as an engineer. Our experience shows that it is a decided advantage that every subject taught in engineering schools should, as far as practicable, be taught by engineers or specialists practically familiar with engineering and its applications of their subjects. We even find great advantage in securing instruction in applied mechanics from members of the profession having a talent and special predilection for that subject. The absurdity of establishing engineering schools with non-professionals at their heads has slowly come to be recognized to be as great as that of the custom, formerly general, of putting a clergyman, as such, at the head of every college, and the folly of seeking to construct an engineering course to be taught by a non-professional is not less patent. It is probably this fact which accounts for the early and steady success of the Troy school, in which, from the first, the "director," the active, working head, has been at home in engineering practice. The organization of any professional school with any other than a professional expert at its head has come to be recognized as eminently absurd and dangerous. Eminent professionals at the head, and talented men practically experienced on the staff, are the primary elements of success in any engineering, as in any other professional, school, and a no less important element of success, perhaps, is also the placing of specialists in charge of special lines of engineering work. This is now always a feature distinguishing the larger and the better classes of technical school and college. A similar fundamental error is observable in the organization of many of the "Land Grant Colleges" established for the special purpose of promoting agriculture and the mechanic arts. The non-professional is placed where the professional should work. A baby should not only be "nursed by one who loves it," but by one who knows what it wants and how to supply it.

† *Engineering News*, August 11, 1892.

The three grades or classes here covering the whole body of engineers in the United States—civil, mining, and mechanical engineers—the latter of course covering, in turn, its subdivisions, the marine, the electrical, and the chemical, and the mechanical engineers of railways—are seen to have grown, in curiously different degrees, from a common small or absolutely insignificant beginning of such growth just at the close of the Civil War, 1865. The numbers of mining engineers increased at the rate of four or five per annum for ten years, then remained comparatively stationary, as measured, at least, by the numbers graduating from the engineering schools and colleges, and with singular fluctuation, up to date. The numbers of the graduates in civil engineering show a steady and rapid increase at the rate of about ten per annum, as an average, for the whole period. From 1865 to 1875, however, the increase is uniform and about **fifteen** per year, while between 1875 and 1882 there is an actual falling off at the rate of ten per year; the upward rise then recommencing at the old rate and continuing at that maximum rate to date. The falling off noted is seen to commence very nearly at the time of beginning of the upward movement in mechanical engineering; but its true explanation is probably to be found in the occurrence, in 1873, of the most serious commercial "crisis" of the generation included in the diagram; which began and ended with the period of depression of the



GRADUATES FROM ENGINEERING SCHOOLS OF THE UNITED STATES SINCE 1860.

Eng. by Am. Bank Note Co. N.Y.

FIG. 325.

line in our diagram, covering about ten years in decline and final recovery.

The course of growth of the mechanical engineering branch is traced on the diagram as the smoothest curve of the set, and is expressed by the equation, $N = 0.5\ T^2$, nearly, dating from 1865. The smoothness of the curve may perhaps be taken as indicating the action of natural causes with less of artificial and accidental disturbance than in the cases of the other lines of engineering, and the steady rise to the end of the period would seem to show that that set of causes is still operating and likely to continue its action in the immediate future, at least. Something like one-half of this recent growth is probably in one branch, electrical engineering, and it is also the fact that the introduction of the applications of electricity—stimulating, as it has, the work of every other branch of mechanical, and, indeed, to no small extent, of civil, engineering, producing such an expansion of the use of steam and the steam-engine as has not been seen since the days of Watt—has similarly increased the demand for mechanical engineers in the "regular" branch.

Another and possibly still more important factor in the promotion of the growth of this branch of engineering is very probably the circumstance that the mechanical engineer finds a larger number of lines, of distinct vocations, opening to him than does any other member of the profession of engineering. The steam-engine building establishments which besprinkle the whole country; the railways with their hundreds of repair and construction shops; the great manufactories of electrical machinery; the street railways employing electrical energy; the cotton and the woollen mills; the tool-builders; the country repair-shop, even—all these and a thousand less familiar lines of business are calling for men educated sufficiently to make good and properly proportioned designs for machinery of all kinds, men to superintend their construction and to see them properly erected and set in operation, and engineers competent to build the establishments intended for building machinery of all kinds. It thus happens that not more than one-half of the engineers of the country, graduated from our engineering schools, remain in the lines of work originally selected. The others drift continually into other and to them more attractive, more remunerative, or more available fields. It has thus happened that in the decade 1880–90 the number of men in this branch increased more than ten times, while in civil engineering the gain

was but one-fourth as large, and in mining engineering there has been a falling off, both absolutely and relatively. In the latter division the number at its maximum, in 1884, was but about sixty graduates in all schools throughout the United States; a somewhat remarkable fact, the extent of the mining interests and their importance in this country being considered. Of those taking this work the Columbia College "School of Mines" has graduated by far the larger number, often two-thirds or more of the whole list. Fourteen other schools supply the remainder of the list of from thirty to fifty graduates; the average for all being, of late, about three each per annum.

The American Society of Mechanical Engineers was founded in the autumn of 1880, and has had a very rapid and continuous growth from that date. It is not at all impossible that the formal organization of the profession, which thus took place in this country, had something to do with the contemporaneous growth of the mechanical engineering schools and the coincident and rapid rise in numbers of graduates from our engineering schools in this branch. A glance at the diagram shows the two bodies to have had a similar and nearly proportional increase; the numbers of graduates in mechanical engineering being approximately one-fourth the numbers of the Society in which their seniors were uniting. The formal establishment of a professional nucleus, and the influence thus exerted upon the young "natural mechanics" of the country, is not unlikely to have promoted effectively the growth of schools of this class. The influence of that Society and of its more distinguished members has certainly been most favorable to the establishment and advancement of this phase of professional education, and to the elevation of their courses of instruction to a plane never yet reached by any other professional schools.

THE AGRICULTURAL COLLEGES, so called, are the "colleges of agriculture and the mechanic arts" which have been established by the various States receiving the grant of the Federal Government in 1862 and founding separate colleges under that contract. In many cases these colleges are departments of the State universities, but in other cases they are independent and separate institutions. The title is not a new one, nor is the agricultural college a novelty. The Royal Agricultural College of Cirencester, England, was founded, in 1845, by a company of English noblemen, led by Prince Albert. It has no endowment, and charges £75 per annum for instruction, and £135 for all items where the student is also given

a home at the college. There are now several colleges of this kind in Great Britain, and large numbers of schools of agriculture and of forestry have been established on the continent of Europe, having somewhat similar purposes. The result of their operation has been the production of a system of scientific agriculture which has doubled the production per acre in those countries, while the crops in the United States have been steadily falling off from the first. The apportionment of the $16,000,000 realized from the land grant of 1862 among the several States of the Union has led to the permanent foundation, in nearly all the States, of agricultural colleges, and this large sum has been supplemented in many States, if not in all, by considerable grants made by the States themselves. The Act of 1890 also appropriates from the Federal Treasury $15,000 a year, annually increasing $1,000 until the total becomes $25,000 per annum, to each State, for the same object. In most cases "Experiment Stations" are established in connection with the colleges, and these are often productive of large and exceedingly valuable researches. Tuition in these colleges is usually entirely free.

In the majority, if not in all these colleges, the courses of regular instruction are of four years' length; but most of them also make provision for the reception and instruction of special and other short-term students, who are usually not fully prepared to enter upon the full course of systematic study for a degree. A general education is, so far as practicable, also usually incorporated in the professional course, and the endeavor is made, as in most other technical schools, to give both an education and a training in the chosen occupation in four years. The purely professional school is, as yet, practically unknown in this class of institutions.

Experimental farms are always an important part of the equipment of these colleges, and the students are taught by observation, and often by direct experiment, to observe the results of rotation of crops and the use of fertilizers. The breeding of animals, and butter and cheese making, also commonly constitute an essential feature of the course.

Since Prof. W. O. Atwater established the first of these stations in the United States, there have been founded about 55. Most of them came into existence after the passage of an act of Congress, in 1887, giving $15,000 to each State for the foundation of such stations in connection with the agricultural colleges; at the date of which law there were only 17 in existence. Those now in operation employ about 400 trained specialists in the work of investiga-

tion. For this work the Federal Government now appropriates annually about three-quarters of a million dollars, and the States add to this sum about $150,000. Thus nearly a million of dollars is annually expended in research for the benefit of agriculture. The work is largely specialized, often one station assuming the work of studying the production of cream, another that of butter and cheese, and another the fertilizers, or the special lines of stock-breeding that may be most suitable to its surroundings and the requirements of the people in its State.

The Western colleges are well attended by young agriculturists; but agriculture is far less attractive to the rising generation in the East, and attendance is there comparatively small. The total attendance in all the States is about 6,000 (1893).

The U. S. Department of Agriculture constitutes one of the several principal Government departments of which the heads are the members of the President's Cabinet. It was made a bureau originally (1862) under the Interior Department, and was erected into a department in 1889, with a Secretary of Agriculture at its head. It now includes fifteen sub-departments, and each is doing a large amount of valuable scientific work, and publishing results in its regularly issued bulletins for distribution to the agriculturists of the country.

Its work consists largely in the introduction of new varieties of domestic animals, new fruits, grains, vegetables, and in the distribution of seeds and other useful material to the farmers of the whole United States. It keeps watch of the sanitary condition of the country and of herds, provides for the reduction of epidemics and their prevention among domestic animals, prevents the adulteration of food products, and furnishes regular and frequent reports upon the condition of the growing crops. It coöperates with the agricultural colleges and experimental stations in the work of research and, in general, promotes the interests of the agriculturist in all practicable ways.

The U. S. Department of Mechanic Arts does not exist, nor is there any special appropriation for this section of the work of the colleges founded for the benefit of "the industrial classes," either by the Federal Government or any State. The wonderful growth and flourishing condition of these colleges is due, wholly in many cases, greatly in all cases, to the sympathy and assistance given by private liberality. The bureaux of statistics of labor are the only governmental organizations doing anything specially to promote

the interests of this section of those classes, and they can do but little more than to aid the worker in finding the best market for his labor; they can do nothing to promote his education and to advance his experimental knowledge as do the "experimental stations" of the agriculturists. The establishment of a Department of Mechanics, similar to that now long organized for agriculture, was proposed twenty years ago by the late A. S. Cameron, of New York, but never obtained recognition, and nothing has been accomplished, even if anything has been attempted, since. The work which should be performed by such a department at Washington is done, so far as it is done at all, by the engineering schools and colleges, some of which have good departments of research and fine engineering laboratories. It would seem probable that, with the organization of such a department, under proper officers, the present neglect of the interests of these industrial classes might terminate, and even our Patent Office be placed on a correct and equitable basis.

THE ACT OF 1887, supplementary of the Morrill Bill of 1862, provides that each State and Territory sustaining colleges for the benefit of agriculture and the mechanic arts shall receive from the Treasury of the United States $15,000, to be expended in the establishment of an agricultural "experiment station," in which to conduct investigations relating to the science of agriculture and in the development of the practice of systematic agriculture. These stations are about fifty in number, and now publish an enormous amount of useful matter in the form of reports upon the subjects of their investigations.

THE ACT OF 1890 also supplemented the Morrill Bill, by appropriating $15,000 annually from the U. S. Treasury for the purposes of the "agricultural and mechanics arts colleges," increasing the amount $1,000 a year up to a maximum of $25,000 annually. As in the Act of 1862, it is provided that no part of this sum shall be expended upon buildings, that duty being assumed by the States accepting this gift from the general Government. The result of this liberality on the part of the Federal Government is the publication on an average of over fifty reports annually by these colleges, and the instruction of large bodies of students in the best methods of scientific investigation as well as in the theory and practice of scientific agriculture. In the Western States, these agricultural experiment stations turn their attention to matters affecting the production of the grains; in the East, more generally to dairy work.

The extent to which the States sometimes contribute to the furtherance of the special interests of the agriculturist is seen in the following, excised from the message of the Governor of New York for 1892–93:

"At the last legislative session $279,000 was appropriated in different measures for agricultural purposes, and the mere statement of the several objects of expenditure indicates the random and heterogeneous character of the legislation, viz.: $20,000 to the New York Agricultural Society for premiums at the State Fair; $20,000 to the same society for distribution to county agricultural societies and to the American Institute, for premiums; $8,000 each to the New York and New England Agricultural Society, the Western New York Agricultural Society, and the Inter-State Fair; $40,000 to the State Agricultural Experiment Station at Geneva: $18,500 additional to this station for various purposes; $95 000 to the Dairy Commissioner; $5,000 additional to the Dairy Commissioner for the employment of experts; $4,500 for the State Meteorological Bureau; $15,000 for the maintenance of farmers' institutes under the direction of the State Agricultural Society; $5,000 for promoting and extending dairy knowledge and science, to be expended under the direction of the State Dairymen's Association; and $32,443.95 to the State Agricultural Society out of the receipts from racing associations."

"The annual cost of all the constitutional departments of State government is not so great as the sum of last year's appropriations for the miscellaneous legislative agencies created for promoting agriculture," and the Governor recommends the concentration of all the scientific work of the State in this department at the State university—Cornell—and the placing of the miscellaneous work above catalogued in more compact form. Statistics of this kind are not at hand for Western States; but there is no question that they are, as a rule, also exceedingly liberal to the agricultural interests.

THE PRINCIPLES which underlie the planning of a course of systematic instruction in engineering are obvious and clear; but no two authorities have given them precisely the same enunciation. One of the most concise and definite statements which have yet appeared is perhaps that of Professor Lanza:*—

(1) The proper function of such a department of instruction is to

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* *Trans. A. S. M. E.* Vol. VII., Boston Meeting, 1885.

drill the student in the theoretical (especially mathematical and physical) principles that underlie his profession, and to conduct this drill in such a manner that he may be able to apply them to the practical cases that he will meet after he leaves the school and enters active life.

(2) If, instead of this, the student is taught to depend upon formulæ, hand-book rules, or rule-of-thumb methods, instead of upon his own power of applying principles to the solution of his problems, he has not been given the education that he has a right to expect.

(3) In order to accomplish the objects stated, as large a practical element as time will allow should be introduced, in the recitation room, the drawing room, and the laboratory. This practical work should always follow and not precede the theoretical instruction bearing upon it. The student should be made familiar with the machinery which is to be found in the market to-day, and the models used in instruction, the illustrations and the practical applications of his theory should all have to do with modern machinery and not with obsolete or impracticable combinations, and the style, system, conventions, etc., used in the instruction in drawing should be such as would be suitable for use in a draughting office.

In the laboratory he should be drilled in just such work as he will meet with in the practice of his profession, and this work, such as boiler tests, engine tests, measurements of power, etc., should be carried on with machinery of such proportions as would be employed by the engineer, and the conditions of working and the methods of conducting the experiments should be those suitable for use in practice.

He should be taught to perform his experimental work with the care and accuracy necessary to insure results of real value, and he should also be made to carry on experimental investigation.

(4) Besides this, he should have a good course in shop work; and his graduating thesis should consist of something which he has investigated for himself, the chief value of the thesis being, in my opinion, the practice the student acquires in carrying on original investigation on his own account.

(5) Any attempt or claim of a technical school to give a student an education which will supersede that given subsequently by experience in practice, or to send him out an accomplished engineer, is futile and impossible.

In all such courses of instruction should be included, according to the expressed judgment of probably a large majority of the educated members of the profession:

(1) Mathematics, Physics, and Applied Mechanics; the last including the strength of materials.

(2) Recitation-room work.

(3) Drawing-room work.

(4) Shop or field work, or both.

(5) Laboratory work.

All recognized engineering colleges give these several lines of work; but no two give the same amount, either absolutely or relatively. The quantity of work performed in the mathematics depends upon the preparation which can be obtained for entering students preliminarily to their taking up the college course, upon the extent to which the applied mathematics and professional work of the course requires and presupposes mathematical knowledge, and in some cases, perhaps usually, partly upon the inclinations and prejudices of the instructors, who are prone to call upon students for the kind of work familiar and interesting to themselves in larger amount than is absolutely needed in the prescribed work of the course. It sometimes even happens that a distinguished professor of pure or applied science gives his attention largely to matters of comparatively little importance to his pupils, though of great interest to himself, to the neglect of the backbone of his course. The mathematical expert is peculiarly liable to this mistake, and often carries his students into the speculative and abstract branches of his subject, greatly to the detriment of his professional work and of his applied mathematics.

This is one of the reasons why it is usually considered important that the applied mathematics, perhaps the pure mathematics, also, should be taught in all technical schools by the man of a practical turn of mind and with some practical experience in the use of mathematics in the solution of the problems of the practitioner in engineering. The mathematics must be regarded as a chest of tools, and their use should be taught by the expert tool-user, not by the maker or the fancier. As in invention, the constructor usually disposes of the inventor as soon as the device is perfected, and gives the business of manufacturing into the hands of the manufacturer; so, in the use of the mathematics, it seems often desirable to divorce the two branches and to give to the mathematician the task of developing the processes of the subject and to the pro-

fessional the illustration of their most important and useful applications. The same principle is seen in the development of the electrical branch of mechanical engineering. The physicist succeeds best in the revelation of the principles and facts and phenomena of pure electrical physics; but it is the engineer who must exhibit and illustrate the applications of that knowledge in the construction of the machinery with which he has to produce and distribute that form of energy for useful employment in engineering. Precisely where and how these divisions of the great work of technical education can best be made, is not always easily determinable; but we are rapidly gaining an experience which will soon give us the means of properly apportioning the work for our purposes.

THE IDEAL COURSE of instruction in the higher technical schools would undoubtedly include in the main the application of the principles here given and the introduction of all the several divisions of the professional work of the engineer, for instance, which have been above enumerated. But no course of instruction can fully meet the requirements of the ideal, mainly in consequence of the fact that time is restricted, with even the best of our schools, and even with full four-year courses. The following scheme was perhaps the first ever published as an ideal, in our country at least, and gives some idea of the form which such a scheme takes in the mind of a practitioner. It was formulated, much as here presented, in the spring of 1871, and finally printed, after some reconstruction in the light of the friendly criticisms of the most distinguished engineers of that time, and distributed among those interested in the work.*

COURSE OF INSTRUCTION IN MECHANICAL ENGINEERING.

I.

MATERIALS USED IN ENGINEERING.—Classification, Origin, and Preparation (where not given in course of Technical Chemistry), Uses, Cost.

Strength and Elasticity.—Theory (with experimental illustrations) reviewed, and tensile, transverse, and torsional resistance determined.

Forms of greatest strength determined. *Testing* materials.

Applications.—Foundations, Framing in wood and metal.

* *Scientific American Supplement*, April 19, 1884.

FRICTION.—Discussion from Rational Mechanics, reviewed and extended.

Lubricants treated with materials above.

Experimental determination of "coefficients of friction."

II.

TOOLS.—Forms for working wood and metals. Principles involved in their use.

Principles of pattern making, moulding, smith and machinists' work so far as they modify design.

Exercises in Workshops in mechanical manipulation.

Estimates of *costs* (stock and labor).

MACHINERY AND MILL WORK.—Theory of machines. Construction. Kinematics applied. Stresses, calculated and traced. Work of machines. Selection of materials for the several parts. Determination of *proportions* of details, and of *forms* as modified by difficulties of construction.

Regulators, Dynamometers, Pneumatic and Hydraulic machinery. Determining *moduli* of machines.

POWER, transmission by gearing, belting, water, compressed air, etc.

LOADS, transportation.

III.

HISTORY AND PRESENT FORMS OF THE PRIME MOVERS.

Wind-mills, their theory, construction, and application.

Water-wheels. Theory, construction, application, testing, and comparison of principal types.

Air, Gas, and Electric Engines, similarly treated.

STEAM ENGINES.—Classification. [Marine (merchant) Engine assumed as representative type.] Theory. Construction, including general design, form and proportion of details.

Boilers similarly considered. Estimates of *cost.*

Comparison of principal types of Engines and Boilers.

Management and repairing. Testing and recording performance.

IV.

MOTORS APPLIED TO MILLS.—Estimation of required power and of *cost.*

Railroads. Study of Railroad machinery.

Ships. Structure of Iron Ships and Rudiments of Naval Architecture and Ship Propulsion.

PLANNING Machine shops, Boiler shops, Foundries, and manufactories of textile fabrics. Estimating *cost.*

LECTURES BY EXPERTS.

GENERAL SUMMARY of principal facts and natural laws, upon the thorough knowledge of which successful practice is based; and general *résumé* of principles of business which must be familiar to the practicing engineer.

V.

GRADUATING THESES.

Accompanying the above are courses of instruction in higher mathematics, graphics, physics, chemistry, and the modern languages and literatures.

This course of instruction was intended to be introduced, with the approval of substantially all the most prominent members of the profession, who were at the time consulted, into the curriculum of the Stevens Institute of Technology, to which institution the writer had then been called as Professor of Engineering. That institution had been founded as a school of mechanical engineering, purely; and it was thought possible, there, to give as full a course as is here laid down. The event proved this assumption to be a mistake, and indicated that, even in a special school of engineering of this character, it is not practicable, in the time allowed for the professional studies of its four years' course, fully to cover the ground here proposed.

The next scheme is one proposed recently by Mr. Wm. Kent in the course of a discussion on this general subject in connection with the paper of Professor Alden, of Worcester, from which the preceding is also extracted, thus:—

Freshman and Sophomore Years. All Students.

MATHEMATICS.—Finish differential calculus by the end of the sophomore year.

FRENCH AND GERMAN.—With special reference to technical translation.

FREE-HAND DRAWING.—Only so far as to give facility in sketching, and a knowledge of the principles of art so far as they may be applied to engineering constructions.

MECHANICAL DRAWING.—Including the use of instruments, pro-

jections, shades and shadows, perspective and isometric drawing, line shading, tracing and blue-print work, and drawing from copy.

CHEMISTRY AND PHYSICS.—Lectures and text-book work.

SHOP WORK.—Elementary instruction in carpentry and pattern making, the uses of machine tools, bench work, foundry work, blacksmithing, pipe fitting, etc. The course up to end of the sophomore year being strictly one of instruction, after the Russian system, or a modification of it, in which the learning of how to do work is the object in view, and not the making of any product for sale.

MECHANICAL ENGINEERING.—Lectures and instruction in the materials of engineering and machine-shop practice.

Junior and Senior Years.

a. Course in Mechanical Engineering.

MATHEMATICS.—Integral calculus, and application of same to mechanics.

MECHANICS OF ENGINEERING.—A thorough course in Weisbach or equivalent text-book.

KINEMATICS.—Reuleaux, or equivalent text-book.

PHYSICS.—Laboratory practice, with special reference to the mechanics of fluids, heat, and electricity.

CHEMISTRY.—Laboratory work in inorganic, with reference especially to metals and their ores.

MINERALOGY.—Determinative, with blow-pipe analysis.

GEOLOGY.—Elements of economic, with reference to fuels, ores of metals, fire-clays, etc.

LITHOLOGY.—Elements of practical.

(These last four subjects may be optional in the senior year for students who wish to study mechanical engineering as applied to metallurgy. Physical laboratory practice in electricity, and kinematics, may be omitted by such students.)

MECHANICAL DRAWING.—Difficult problems in drawing, designing of machinery and plants, and original problems. In this course the aim should be not to make expert handlers of instruments, but men capable of doing original and varied work on the drawing board, and of laying out work for execution by other draughtsmen.

SHOP WORK.—Carrying into practice in the shop the constructions studied in the drawing room, and studies of the work being

done by the students of the machine-shop course; the idea being not to make the students expert with their own hands, but to instruct their heads, so that they will know the difference between good and bad work done by others.

MECHANICAL ENGINEERING.—A course of instruction under the head of the department in the general subjects of engineering design, the theory of prime movers, the mechanical theory of heat, steam boilers and engines, work in the mechanical laboratory in tests of materials and other experiments, and lectures on metallurgical plants and methods.

CIVIL ENGINEERING.—So much as relates to building materials, foundation and the theory of strains in bridges and roofs.

MARINE ENGINEERING.—Lectures or other instruction in naval architecture and engineering, and marine practice.

b. Course in Machine-Shop Practice.

MECHANICAL DRAWING.—Such a course of instruction as should make the student expert in carrying out ideas originated by others, including so much knowledge of the strength of materials as is necessary to correct designing; also to make him a fine workman with draughting tools.

SHOP WORK.—A thorough apprenticeship in the machine shop, with not less than five hours' work per day for six days in a week, the shop to be carried on according to the best outside machine-shop methods, with the exception that the end in view must not be the obtaining of the maximum profit from the work of the shop, but the maximum of instruction given to the apprentices. The work should be of as varied a character as possible.

MECHANICAL ENGINEERING.—Attendance upon such lectures by the head of the department as may relate to machine-shop practice without involving the application of the higher mathematics.

"Throughout the whole four years' course, both in mechanical engineering and in work shop practice, all students should be required periodically to write essays or reports on subjects connected with their work, which are to be criticised by the head of the department as to both matter and manner."

In order that such courses of professional instruction as these may be properly carried out, it is evident that every instructor engaged in the work should be familiar with the demands of practical life and of professional work. Not only should the professor of mechanical engineering be a practitioner, and thoroughly versed in

the art as well as the theory of his profession, but the teacher of drawing should be equally familiar with actual work; not simply the principles of descriptive geometry and the methods of the drawing room should be familiar to him, but he should be expert in designing, and should be capable of teaching the student all the details of calculating, forming, and proportioning the parts of all familiar machinery. The art of designing must necessarily be largely taught in the drawing room, since it can only be satisfactorily practised with the aid of the apparatus of the drawing-room. The course of instruction in the lecture rooms should furnish the requisite knowledge of principles and of the facts relating to the strength and other properties of materials, and the modifications of design necessitated by the exigencies of construction; but the actual designing must be done in the drawing room, and the course of instruction there, beginning with the principles of graphics, should lead, at the earliest possible date, into the work of laying out the parts of machinery.

The instructor in the workshops should also be educated in, and at home with, the principles, as well as the practice, of his art; and even the teachers of mathematics, the instructors in the languages —in fact, every one who takes a part in the work of educating the young engineer—should be familiar with the applications which the student is to make of the knowledge which he is to communicate to him.

THE COURSES ACTUALLY TAUGHT necessarily fall short of the ideal; but they are gradually approaching it more closely in kind and in time. A glance over the various curricula of any large institution in which technical studies form any important part of the work, as conducted in the United States, will show to what extent these ideas are adhered to and how far each of the fundamental divisions of the professional course is developed in the operation of the technical school. The following table, for example, which is abstracted from the current issue of the catalogue of the Massachusetts Institute of Technology, shows what subjects of each class are taken, the method of instruction—whether in class-room or laboratory or field—and the time there given to each, in engineering work.

CIVIL ENGINEERING.

Subject.	Lect., Rec., Lab., Draw., or Field.	Year.	Term.	No. of Weeks.	Hours per Week.
Surveying	Lect., Rec., Field. Draw.	2	1, 2	30	6, 5 5, 6
Surveying	Lect., Field.	2	1	15	4
Topographical drawing	Draw.	2	1	15	2
Elements of astronomy	Lect., Rec., Field.	2	1	15	1
Surveying	Lect., Rec., Field. Draw.	3	1, 2	30	2
Surveying instruments (six lessons)	Lect., Field.	3	2	.....	.....
Railroad and highway engineering	Lect., Rec.	3	1, 2	30	2
			1	15	4
Railroad field-work and drawing	Field.	3	2	15	5
	Draw.		1, 2	30	2, 5
Stereotomy	Lect., Draw.	3	1	15	4
Theory of structures	Lect., Rec.	3	2	15	2
Railroad and highway engineering	Lect., Rec., Draw.	4	1, 2	30	3
Railroad management	Lect.	4	1	15	2
Geodesy and practical astronomy	Lect., Rec., Field.	4	1	15	3
			2	15	6
Geodesy and practical astronomy	Lect.	4	1, 2	30	1
Geodetic surveying	Lect., Field.	4	1	15	2
		4	1	15	3
Theoretical hydraulics	Lect., Rec.	4	1	7	2
Sanitary and hydraulic engineering	Lect., Rec.	4	1	15	3
Hydraulic measurements	Field. Draw.	4	1	15	2
Theory of structures	Lect., Rec.	4	1, 2	30	2
Theory of structures	Lect., Rec.	4	1	15	2
			2	15	3
Bridges and similar structures	Lect., Rec.	4	1, 2	30	2
Bridge design	Draw.	4	1, 2	30	6
		4	1	15	4
Hydraulic motors	Lect., Rec.	4	2	15	2
Hydraulic engineering	Lect., Rec.	4	2	15	3
Engineering laboratory	Lab.	4	2	15	3
Railroad and highway design	Draw.	4	2	15	2
Sanitary and hydraulic designing	Draw.	4	2	15	2

MECHANICAL ENGINEERING.

Subject.	Lect., Rec., Lab., Draw., or Field.	Year.	Term.	No. of Weeks.	Hours per Week.
Principles of mechanism	Lect., Rec.	2	1	15	2
Drawing	Draw.	2	1	15	2
		2	2	15	6
		2	2	15	3
		2	2	15	4
Mechanism: Construction of gear-teeth, machine tools, cotton machinery	Lect., Rec.	2	2	15	3
Mechanism: Construction of gear-teeth, machine tools	.....	2	2	15	2
Principles of mechanism	Lect., Rec.	2	2	15	2
Steam engineering: Valve gears, boilers	Lect., Rec.	3	1, 2	30	3
Drawing: Design	Draw.	3	1, 2	30	6
		3	1	15	5
		3	1	15	3
			2	15	2
		3	1	15	6
			2	15	2
Engineering laboratory	Lab.	3	2	15	2
Steam engineering	Lect., Rec.	4	1	8	2
Dynamics of machines	Lect., Rec.	4	1	9	3
		4	1	5	3
Machine design	Lect., Rec., Draw.	4	1	15	8
Naval architecture	Lect., Rec., Draw.	4	1, 2	30	8, 6
Engineering laboratory	Lab.	4	1, 2	30	4
		4	2	15	4
Locomotive construction	Lect., Rec.	4	1	6	2
			2	15	3
Marine engineering	Lect., Rec.	4	1	6	2
			2	15	3
Mill engineering	Lect., Rec.	4	1	6	2
			2	15	3
Technical machinery	Lect.	4	2	15	2

MINING ENGINEERING.

Subject.	Lect., Rec., Lab., Draw., or Field.	Year.	Term.	No. of Weeks.	Hours per Week.
Blowpipe silver assay	Lab.	2	1	15	2
Mining engineering	Lect.	3	1, 2	30	3
		4	1	15	3
Assaying by fire	Lab.	3	2	15	4
		3	1	15	2
		4	2	15	2
Metallurgy of iron	Lect.	4	1	15	1
Metallurgy of non-ferrous metals	Lect.	4	1	15	2
Mining	Lab.	4	1	15	8
			2	15	12
Metallurgy	Lab.	4	1	15	8
		4	1, 2	30	8, 12
Mining engineering	Lect.	4	1	15	2
			1, 2	30	
Metallurgy of non-ferrous metals and general metallurgy	Lect.	4	2	15	3
Memoirs (sec 137)	Read.	4	1, 2	30	2

ARCHITECTURE.

Subject.	Lect., Rec., Lab., Draw., or Field.	Year.	Term.	No. of Weeks.	Hours per Week.
Orders	Lect., Rec., Draw.	2	1	15	2
Shades and shadows	Lect., Draw.	2	1	15	1
Perspective	Lect., Draw.	2	2	15	1
Materials	Lect.	2	2	15	1
Design	Draw.	2	2	15	4
Pen and ink	Draw.	2	2	15	1
Architectural history	Lect., Draw.	2 3 3 4	2 1 2 1	30	1
Specifications and working drawings	Lect., Draw.	3	1 2	15 15	1 2
Stereotomy	Lect., Draw.	3	2	15	2
Design	Draw.	3	1 2	15 15	9 15
Pen and ink	Draw.	3	1, 2	30	1
Water color		3	2	15	2
History of construction	Lect.	4	1	15	1
History of ornament	Lect., Draw.	4	1, 2	30	½
Advanced design	Draw.	4	1 2	15 15	16 24
Water color		4	1, 2	30	2
Life class	Draw.	4	1, 2	30	4
Graphical statics	Lect., Draw.	4	1 2	8 7	2 2
Business relations, contracts, etc	Lect.	4	2	15	1
History of painting and sculpture	Lect.	4	2	15	1
Modelling		4	2	15	2
Building construction	Lect.	4	2	15	1

As an interesting example of the method found desirable in the apportionment of the work in a characteristic subject, the following may be taken in illustration of the shop courses of an institution which has always made this subject a very prominent one in its mechanical engineering department, the Worcester Polytechnic Institute. The scheme here given was recently reported to the American Society of Mechanical Engineers.

Practice for students in the department of Mechanical Engineering.

		Processes, Tools and Machines.
Wood work. (Apprentice Class.)	Bench Work.	Laying out work with knife and pencil, the use of planes, hand saws, chisels, squares and gauges.
	Turning and Sawing.	Use of power lathes and the tools for turning hard and soft wood, use and care of circular saws and scroll saws.
	Shaping, Boring, Mortising and Tenoning.	Cylinder, "Daniels," "buzz," planers, shaping and moulding machines, horizontal and upright boring machines, mortising and tenoning machines.
	Pattern making, Moulding and Casting.	Plain, square work, built-up work, turning, chucking and core box-making, core-making, tempering sand for moulds and cores, making cores and moulds, mixing, melting and pouring metal.
General Machine Shop Work. (Junior and Middle Classes.)	Bench Work.	Filing, chipping, tapping, reaming, scraping, and fitting plane surfaces, and finishing with oil-stone and emery cloth.
	Lathe Work.	Drilling and countersinking, filing, polishing, hand-tooling and squaring up.
		Proper speeds for cutting metals, turning to exact size and calipering, cutting threads, squaring up and finishing nuts, chucking straight holes, reaming, inside boring, boring with boring-bars and fitting bearings.
	Drilling, Milling and Planing.	Drilling with speed lathe, upright and traverse drillers; use of Universal milling machine, milling nuts, bolts, heads and studs, cutting splines, fluting taps and reamers, and cutting gears.
		Instruction in use of planer, planing surfaces and bevels.
	Machine Screw Making.	Making machine bolts with revolving head screw machine, cutting up stock, making screws and studs and tapping nuts.
	Tool Making.	The correct forms of turning tools and the principles of grinding them; making taps, dies, reamers, twist drills, countersinks, counterbores, mills, milling machine, cutters, mandrels, boring bars, chuck drills, and centers, forging and tempering steel.
	Management of Steam.	Care of boilers and engine, including the work of firing, the care and control of the steam pressure and the water supply; also the care and manipulation of the steam pump and injectors. The practice in the steam department is under the constant oversight of the engineer.
Construction of Special Machines. (Senior Class.)		A part of senior practice consists in draughting, setting-up and putting in operation some machine of sufficient complexity to allow all the members of the class to take a responsible part in the work. This work differs from the general practice in this respect: viz., that it is especially the work of the senior class and not liable to be partly the work of journeymen. For list of machines constructed see next column.
Work in Draughting-Room. (Senior Class.)		Making working drawings, blue prints and tracings for use in shop. Designing tools and machines.

Products of Washburn Machine-Shop.

(Average annual sales for fourteen consecutive years, $15,374.51.)

Samples of frame-work, mortised and tenoned and dove-tailed (2 weeks).

Boxes, simple carved brackets, book-shelves, foot-rests and cabinets.

Patterns and core-boxes for casting the following pieces; plain platen, ribbed platen, flange coupling with recess and core, cylinder, cored cylinder with chambered core, slide rest with dove-tailed gib moulded with loose pieces, tool post with square core, oil cup cover with balanced core, two groove pulleys, one cored, moulded in three parts, white metal castings from each of these patterns.

Cabinet-work, wall cabinet, book-cases and writing desks.

Machinists' tools, engine and speed lathes, with hardened steel bearings.

Revolving head and screw machines, and hardened steel mandrels.

Chuck drills, bench centers, and lathe tools.

Emery grinding machinery of every description.

Hydraulic elevators, presses, accumulators, and general hydraulic machinery.

Drawing models, improved adjustable drawing tables, drawing boards and T squares.

All iron and wooden apparatus for chemical laboratories, lamp stands, concentric ring stands, test-tube racks.

Apparatus for physical laboratories, including the Willis system of apparatus for the use of lecturers and experimenters in mechanical philosophy, complete working machines illustrating the movements of the link and valve.

C. H. Morgan's machine, showing the correct forms for cams and their movements.

Twenty-five H. P. Corliss engine.

Ten H. P. upright, reversible engine.

Forty H. P. Buckeye engine.

Thirty H. P., high speed, straight line engine, 26″ engine lathe, 16′ bed.

THE REQUIREMENTS FOR ADMISSION to the better class of technical schools of the United States are, on their face, lower than those specified for entrance into the older class of colleges of good repute. This is, however, at least in part, only apparent. The age of the student on entering is substantially the same for both classes, and it is unquestionably the fact that both have given, at their entrance upon collegiate work, the same amount of time to their earlier studies and preparatory education, and must therefore be, so far as time and period of study are concerned, equally advanced. The difference is simply, in most cases, that the student preparing for the literary and classical courses of the older curricula has taken a larger number and more extended line of specified studies than his comrade, who has been, meantime, pursuing "electives" of his own choice, and has usually acquired a better knowledge of mathematics, the modern languages, and the physical sciences than the pupil of the "Latin school," who has had his course marked out for him, in the college requirements, and with great minuteness. The average requirements of the technical schools of good standing include, usually, among other subjects, the following:

	No.	Per cent.
(1) The common school branches	54	97
(2) Physical Geography	27½	49
(3) English Literature	27	48
(4) English History	22½	40
(5) American History	45	80
(6) Elementary French, German, or both — French	15½	28
(6) Elementary French, German, or both — German	11½	21
(7) Algebra through Quadratics	46	82
(8) Geometry, Plane	48	86
(9) " Solid	24½	44
(10) Elementary Physics	22	39
(11) " Chemistry	12¼	22
(12) " Botany	9¾	17
(13) Trigonometry	9¼	16

In any one school or technical college, these requirements are constantly rising, as it becomes possible to demand more and more of the preparatory schools from which it draws its students, and as it becomes thus practicable to throw out one after another of the more elementary studies taught as a part of the technical course, and to thus make the latter more and more purely professional or technical. It has often been proposed to institute one common and universal set of entrance requirements, leading into a similar common course of instruction in the engineering schools; but it is evi-

dent that this is not likely to be accomplished so long as it is possible for the schools of one State to supply its university with students prepared to take up at once technical reading in foreign languages and the most advanced text-books in applied mathematics, and to enter at once upon laboratory work in chemistry and physics: while those entering the colleges and technical schools of another State are prepared by schools unable to give their pupils instruction above the grade of elementary algebra, plane geometry and, generally, the studies of the lower grades of high school; or so long as it is found practicable in New York State to organize a school of engineering, as purely professional as the school of law or of medicine of the highest class, while in neighboring States the same work must be attempted in schools in which two years of common school education must be incorporated with the professional work, and the student thus offered a mixed educational and professional course of four years' or even of but three years' length. The tendency is, however, in all, to rise toward the plane of the purely professional school.

THE COST OF EDUCATION in this country varies immensely, accordingly as the instruction in the institution considered is of a lower or higher grade, is given by lecture or by text-book, is offered to large classes or to a few individuals, and as it involves a greater or a less expense for apparatus and its use. Electives taught in the larger colleges, by distinguished and costly faculties, to comparatively small numbers of advanced students, and laboratory, and especially engineering laboratory, work in the technical schools, are expensive methods and subjects of education; while lectures to large audiences, text-book work with large sections and given by low-salaried and youthful instructors, are inexpensive. The cost, in fact, is in substantially all cases, the sum of the income from endowments and current receipts of the college, wherever and whatever it may be, added to what it is considered safe or expedient to charge as a tuition fee. With large endowments and small bodies of students, costs are high, as assigned to the individual, and education in some such measure efficient; with small endowments, and also, as is apt to be the case, with small fees, costs are low, and the instruction offered must often lack effectiveness for want of ability on the part of the institution to employ the highest talent of the specialist and to supply the needed apparatus. In the most advanced schools and colleges, the costs range from $200 or $300 per annum per student, up to $500 and $600 and even more. Cornell University may, perhaps, be

taken to represent an average case; the instruction of its 1,600 or 1,700 students costing about a half million of dollars a year, of which about *one-fifth* is received from the students thus benefited, *one twenty-fifth* from the State, in compensation for the annual expenditures on five hundred untaxed students at a cost to the university of $150,000, and the remainder principally from the endowment fund supplied by Mr. Cornell and his colleagues by sales of land located by the former with the land-scrip bought by him of the State, in the early days of the history of the university.

The Rensselaer Polytechnic School obtains substantially all its funds for annual expense accounts from tuition fees, and the Massachusetts Institute of Technology also depends largely on this source of regular income; both charging $200 annually. The Stevens Institute of Technology has a moderate income from its endowments, and receives $175 a year, and in some cases $225, as a tuition fee. The charges for tuition in a large number of institutions of learning are given elsewhere and may be consulted in this connection. It will be seen that the charges for tuition are usually $150 as in many colleges in the West, and sometimes $200 as at Harvard, in special instances in which extensive faculties of specialists, giving elective studies, are maintained. The costs and receipts differ, usually, somewhat, with the different courses taught. These differences are not usually very great, probably are not as great as they should be; that is to say, the costs of a good course in mechanical engineering, or in its now principal branch, electrical engineering, should be greater than those of a course in civil engineering, in consequence of the necessity of employing extensive "plants" of costly machinery; but the machinery is omitted in the outfit in many cases, and the course is then as inexpensive as the other, but less efficient. To the above figures should be added $20 or $25 per annum per student, in the better schools, for this item.

THE CHARACTER AND MAGNITUDE OF THE OUTFIT required by the technical school of higher grade is seldom realized, even by the educator engaged in this department of education. The following is collated from the reports and inventories of the schools of applied science of Cornell University, and shows that over $300,000 have been expended by the university or given by its friends in the collection of its apparatus of instruction; and it is still reported to be desirable that it should be increased to meet the needs of the

still growing student-body. It is, of course, true that this equipment is useful in the university instruction of the students in the "general courses;" but the students in the engineering schools are those who mainly crowd the laboratories of pure, as well as of applied, science, and compel the collection of such immense aggregations of machinery and apparatus. The figures here given are growing at the rate of from $25,000 to $50,000 annually.

Technical library, drawings, etc.	$19,000
Collections, models, etc.	61,000
Surveying instruments	30,000
Chemical laboratory appliances	17,000
Physical " "	43,000
Mechanical " "	54,000
Steam-power plant	31,000
Electrical plant	31,000
Workshop appliances	29,000
Astronomical appliances	13,000
	$328,000

Should the proposed new graduate and undergraduate schools of mining, of railway work, of textiles, and of other branches of engineering be founded, not less than an average of $25,000 each will be demanded for a beginning of their collections, and the amount here given will rise to $400,000, or possibly to even $500,000, if buildings of even an inexpensive character are included. The buildings and equipment of Sibley College, alone, inventory (1893–94) over $350,000, including constructions in progress and their equipments. In the above instance, as in most others in the United States, the collections are made mainly by private contributions, not by purchase by either State or college.

The character of these equipments of the various classes of technical school will, if properly selected, be such as best suits the course to be offered. In every technical school, and even more in the larger than in the smaller among them, there will be found large quantities of often costly apparatus and machinery, contributed, as a rule, by friends of the institution and its work, or by those interested in some special line of investigation, which has little or no value for the purposes of the institution itself, and, while filling the museums and perhaps cumbering the laboratories, finds no place in regular instruction or in general research; but such additions to the inventory add little or nothing to the efficiency of the instruction given, and one dollar expended in the purchase of a piece of

apparatus needed to illustrate the principles of an essential division of the course or to illustrate some point in professional practice is worth more to the student and the school than an indefinite amount expended on the other kind of material. The ideal collection is that in which every item is adapted to precisely fit its place in the work of instruction, and in which every purchase or gift comes into its proper place in a previously well-planned system of instruction. The equipment should be made to fit the course, not the course to fit the equipment. In this respect the outfits of our principal technical schools are generally unique, and nowhere, at home or abroad, can be found such extensive and profitable use of well-adapted material equipments to the work of instruction as in the technical schools of this country giving professional instruction in engineering.

THE CHARACTER OF THE EQUIPMENT, as well as its extent, in a large technical college of the first rank, may be exhibited, perhaps, by the following, abstracted from a catalogue lying under the hand of the writer, and giving the briefest possible inventory of the outfit of the mechanical engineering departments alone:

"The two main buildings are each one hundred and sixty feet long, forty feet in width, and three stories in height. One contains two museums, the library and reading room, drawing rooms, large and well-lighted lecture rooms, and the private rooms of the different professors. The workshops consist of a machine shop, a foundry, a blacksmith shop, and a wood-working shop. The forge and the foundry are in a single detached building. Besides these, there is a building one hundred and fifty feet by forty, and two stories in height, occupied by the laboratories of experimental engineering. At the bottom of an adjacent gorge are the turbines which supply the power required for driving the machinery of the college, and the electric apparatus for lighting the campus and the buildings. The large engine and dynamo room, containing all the engines and dynamos employed in lighting the university, is adjacent to the shops, and beside the boiler-room in which are placed the 1,000 H.P. boilers.

"The two principal rooms on the first floor of the main building are devoted to the purposes of a museum of illustrative apparatus, machinery, products of manufacturing, and collections exhibiting processes and methods, new inventions, forms of motors, and other collections of value in the courses of technical instruction. Here are placed a full Reuleaux collection of models of kinematic move-

ments. Beside these are the Schroeder and other models, exhibiting parts of machinery, the construction of steam engines and other machines. In the museum are placed a large number of samples of machines constructed to illustrate special forms and methods of manufacture. Many machines and tools have been made in the shops. The lecture-rooms are each supplied with a collection of materials, drawings, models and machines, especially adapted to the wants of the lecturer. The course of instruction is illustrated by a collection of steam-engines, gas and vapor engines, water-wheels and other motors, models and drawings of every standard or historical form of prime mover, of parts of machines, and of completed machinery.

"The collections of the department of drawing also include a large variety of studies of natural and conventional forms, shaded and in outline, geometrical models, casts and illustrations of historical ornament.

"The workshops are supplied with machine-tools, including lathes, and hand and bench tools sufficient to meet the wants of two hundred students of the first year, in wood-working; in the foundry and forge, all needed tools for a class of one hundred and fifty in the second year; in the machine shop, machine tools from the best builders, and a great variety of special and hand tools, which are sufficient for a class of one hundred and fifty in the third year, and a hundred and twenty-five seniors and graduate students.

"The department of experimental engineering possesses experimental engines and boilers, and other heat motors, such as air and gas engines, and is well supplied with testing machines in great number and variety, as well as the apparatus required, as indicators, dynamometers, etc., for determining the efficiency of engines.

"The mechanical laboratories constitute the department of demonstration and experimental research, in which not only instruction but investigation is conducted. They are principally located in an annex to the college main building, and occupy its entire area. They are supplied with the apparatus for experimental work in the determination of power and efficiency of motors, and of the turbines driving the machinery of the establishment; with the boiler-testing plant and instruments; and with many machines, of the various standard types, for testing the strength of metals, including one each of 50, 100, and 150 tons capacity; all of great accuracy and delicacy. Numerous steam engines and boilers, air and gas engines, several kinds of dynamometers, lubricant-testing machines, stand-

ard pressure-gauges and a large collection of steam-engine indicators and other apparatus and instruments of precision employed by the engineer in such researches as he is called upon to make, are collected here. All the motors of the institution, and its 600 H.P. boilers, are available for test trials. The steam engines are set up with the heavy lighting dynamos, adjacent to the boilers, and among them, a 200 H.P. 'experimental engine,' and several of smaller power.

"The laboratories of electrical engineering, including the apparatus of the department of electrical engineering and also that available in the department of physics, comprehend many special collections of apparatus. These collections include a great number of large and small dynamos of arc and incandescent lighting types, including a five hundred light and a twenty-five light Edison, two Thomson-Houston, three Weston, a Ball, a Mather, a Waterhouse third brush, a Gramme, a Siemens and Halske, a six hundred and fifty light Westinghouse alternate current machine and its complement of converters, and a Westinghouse forty arc light alternator with its full complement of lamps, a half-dozen each of the one-half horse-power Edison and the 'pony' alternators of Westinghouse; a variety of motors including two ten horse-power automatic Sprague motors, a Brush five horse-power constant current, and a Tesla alternate current motor. Storage batteries are of the Julien, Gibson, Sorley, and 'accumulator' types; aggregating about two hundred cells. There are arc and incandescent lamps of the various types, and commercial electric meters. The great tangent galvanometer and electro-dynamometers, and the potential instrument at the Magnetic Observatory, and the authorized copies of the British Association standards of resistance afford every facility for making measurements in absolute measure of current, E. M. F., and resistance, with the highest attainable accuracy.

"There are large numbers of ammeters, voltmeters, Wheatstone bridges, electro-dynamometers, electric balances, long range electrometers, etc., many here constructed, others purchased, for general use, and always kept in correct adjustment by comparison with the above standardizing apparatus. Apparatus is provided for all delicate testing, for the exact study and determination of alternate current energy, for conductivity and insulation tests, and for the determination of the properties of the magnetic materials. Means for making quantitative measurements are supplied through a well-equipped photometer room for the photometry of arc and incan-

descent lamps: several Brackett 'cradle' dynamometers for efficiency tests of dynamos and motors; a rheostat of German-silver wire, for a working resistance, with a capacity ranging from twenty-two hundred ohms and four ampères, to four-tenths of an ohm and three hundred ampères."

THE MECHANICAL LABORATORY, the department of research of the modern American engineering school, has come to be so important and essential a division of the most successful schools and colleges of engineering, that an article should be specially devoted to this subject. Although not recent in origin or absolutely modern in form and purpose, it is only within a comparatively short time that it has taken its proper place in the organization of these schools and commenced that work which has come, to-day, to be recognized by engineers and educators alike to be the most fruitful of result, the most beneficial to the student, and the most productive of both knowledge and discipline of all the methods of instruction and of study and practice forming parts of the contemporary scheme of engineering professional instruction.

According to the eminent Belgian authority, Monsieur le Professeur V. Dwelshauvers-Déry, the evolution of this form of organization for research began in Europe before it took shape in this country. In fact, the foundation of the Conservatoire des Arts et Métiers in Paris was probably the first step in this direction; and, especially under the direction of General Morin, and later, under Tresca, the prosecution of investigations having bearing upon and value in the work of the engineer became usual directions of research in that great school, and with most important and extensive result. As Laboulaye asserted: "*L'enseignement du Conservatoire des Arts et Métiers est le plus populaire en France. Constitué avec toutes les ressources de la science, initié à tous les dévelopements de l'industrie, dont il a pour mission de faire connaître le progrès, il est pour elle une source féconde de connaissances utiles, un guide sûr dans les applications.*" Of late years, however—since 1885—comparatively little work has been done in this celebrated old laboratory.

As early as 1825 the École des Mines of Stockholm employed a small testing machine in the investigation of the strength of the materials of engineering, under the direction of the distinguished Lagerjhielm; and Gerster, at Prague, at about the same time, perhaps even earlier, performed similar service for engineering science and, with his colleagues, introduced the steam-engine indicator and the brake in the course of his work of instruction. In the year

1836 the École des Mines of Liége was using a collection, including a ten-ton testing machine, indicators, brakes, etc., in its course of instruction; and in 1843 the École des Ponts et Chaussées of Paris was supplied with testing machines for metals and for cement testing. The similar school at St. Petersburg was given an outfit of the same kind in 1853. By 1860 the use of apparatus of investigation in the solution of problems in engineering had become not at all uncommon; although a systematic scheme of organized research or of professional instruction such as the chemists and the physicists had long possessed had not even then taken shape. During and before the Civil War in America, the United States Army and Navy officers had been accustomed to submit all the materials of ordnance and machinery employed by them to systematic test under precisely worded specifications, and the legislation prescribing tests for steam-boilers and their material had become well crystallized; but it was not until about 1870 that engineering schools commenced the introduction of such apparatus and the construction of courses including their use both in instruction and in research.

King's College, London, the University of Edinburgh, and the Polytechnic at Zurich introduced machinery of investigation in 1870. The Munich Laboratory, now under the direction of Professor Schroeter, was planned in 1871 by Professor Linde, whose enunciation of the principles governing its establishment and operation is well summarized in the following remark attributed to him by Dwelshauvers-Déry: "*Il est du plus haut intérêt pour notre école de faire de ce laboratoire un champ d'exercises pour les élèves. Le fait est constaté que le plupart des ingénieurs mécaniciens formés dans nos écoles n'arrivent jamais à faire un usage étendu de leur savoir théorique et en perdent ainsi la connaissance. C'est que, dans ses formules mathématiques, la théorie ne tient pas compte de la variété infinie des conditions qui se présentent dans les cas spéciaux. . . . Sans doute l'abîme qui semble creusé entre la théorie et la pratique n'est qu'apparent pour quiconque a pénétré la science à fond et sait manier avec indépendance les principes; mais ceux-là seuls qui sont doués de talents éminents arrivent à ce résultat. C'est pourquoi l'école doit fournir aux élèves l'occasion de faire eux-mêmes des expériences, d'en discuter les résultats, et d'apprendre ainsi, en les comparant aux données de la théorie, à faire une juste application de celle-ci.*" The learned professor formed his plans and submitted them to his government; but it was five years before he was permitted to offer to his students those facilities for systematic investigation which he had so early proposed.

The plans of the writer for such a laboratory were inaugurated in 1871, when assuming charge of the engineering department of the Stevens Institute of Technology. The construction of a small testing machine was commenced in the following year, and the result of its first application in research, the discovery of "the exaltation of the normal elastic limits by strain," was announced to the American Society of Civil Engineers in 1873. Meantime, the collection of apparatus proceeded rapidly, considering the fact that a loan of a few hundred dollars from the trustees of the school, the private means of the officer in charge, and such profits as could be obtained through commercial work in testing materials and machinery, were the only sources of the required capital. By 1875 the laboratory was so well provided with experimental apparatus as to be prepared to assume the responsibility of carrying on, under the direction of the writer, then the secretary of the "U. S. Board appointed to Test Iron, Steel, and Other Metals," and chairman of several of its numerous committees, such investigations as were assigned him by the board or asked for by other committees of that board. The whole series of investigations of the copper-tin-zinc alloys and a number of other extensive lines of experimental work of investigation were carried on in the laboratory in 1875–78; and some of them becoming recognized as valuable, the standing and reputation of the laboratory were so well established as to make it thereafter a permanent, continually growing, institution for research in engineering.* Its work on the ternary alloys, just referred to, on the lubricants—the first extensive researches in this field—revealing the differences due to varying pressures, temperatures, and speeds of rubbing, and its numerous investigations in all the various fields of modern engineering, have made it a recognized place in the list of such institutions.

For a number of years this laboratory was carried on independently, as a matter of finance, of the school with which it was connected, and the earnings derived from commercial work, sometimes reënforced by the contributions of friends of the movement, paid the salaries of the assistant in charge and of the working force, and even, after a time, began largely to increase its own equipment and added something to that of the department of which it was an adjunct. During recent years it has been dis-

* *Reports of the U. S. Board appointed to Test Iron, Steel, and Other Metals.* 2 vols. 8vo. Washington, Govt. Printing Office, 1875–78.

tinctively a separate Department of Experimental Engineering, and an official connection with the institution has been established.

The engineering laboratories of the Massachusetts Institute of Technology date from about 1873, when Prof. Channing Whittaker commenced the work of collecting apparatus with the aid of Mr. George B. Dixwell, who placed in his hands a steam-engine fitted up with indicators, pyrometers, and accessories required in the prosecution of an investigation of the internal thermal wastes of the engine and the effects of superheating in the reduction of those wastes. The results were published, and attracted great attention at the time. These laboratories now have an exceptionally extensive and costly outfit, including an "experimental steam-engine," a number of testing machines, some of great size and delicacy, and numerous minor apparatus. Its work in research is extensive and extending, and all its students have the inestimable privilege of instruction in this work of investigation of the greater and lesser problems of engineering. The study of the operation of the triple-expansion engine, through the application of the Hirn calorimetric methods by Professor Peabody, and the earlier work of Professor Lanza on strength of heavy timber, illustrate the magnitude and character of its operations. The engineering courses of the institute, like those of every other important school of engineering, are gradually coming to include, in these later years, more and more work of research, and better and better instruction in the methods of exact measurement and of scientific investigation as applied to the problems of every-day engineering practice.

The University of London, in 1875, at the solicitation of Prof. A. B. W. Kennedy, then just installed in the chair of engineering, accepted his plan of an engineering laboratory in that institution, and it was soon after set in operation. It to-day contains, among other apparatus, an experimental engine, heavy testing machines and other important apparatus, and a large amount of good work has been performed by its founder during his connection with the university, and since his resignation by his successors.*

* Professor Kennedy has since established a laboratory of his own for commercial work, following the example of Mr. Kirkaldy, whose work upon the strength of innumerable specimens of every quality of iron and steel, in all forms and under all modes of preparation and treatment, has given us the first and largest contribution of facts in this department.

The École des Mines of Liége, Belgium, has a laboratory, inaugurated by Dwelshauvers-Dery about 1875, described as to its plan and purpose by Hirn in 1876, which has grown slowly but steadily and uninterruptedly from that time to the present.* The work of its founder is well known to all members of the profession who have taken up the examination of this subject, and is likely, in the future, to become still better recognized. It may be said to include the now classic thermal study of the steam-engine, by experimental methods in verification of the work of Hirn; and the development of the existing theory of the thermal wastes on the engine in algebraic form was the natural sequence of his researches.

The South Kensington Laboratory, directed by Professor Unwin, is one of the more recent and more extensive of this class of laboratories of research, and has already given to the world considerable and valuable work. It possesses a special experimental laboratory, and a testing-machine of 100 tons capacity, with such accessories as properly accompany such an outfit.†

The laboratory of Owens College, Manchester, England, that now well-known institution, noted for its work, under the direction of Professor Reynolds, on various calorimetric problems in connection with the operation of the steam-engine, and the still more recent installation of Prof. Hele-Shaw at Liverpool, are other examples of the introduction of systematic investigation as a part of the college work in engineering schools.

The Sibley College laboratory, at Cornell University, is one of the latest and most extensive of those now rapidly taking form in the United States, and especially in the Land Grant and State colleges. It was organized by the writer, in 1885, as a department of instruction, as well as of research, in that institution, and it has come to be already one of the largest and most productive of its various lines of work. It is supplied with a number of testing machines, ranging from 150, 100, 50, and 25 tons capacity down to the smaller torsion, transverse, and impact machines, with several experimental engines of from 150 or 200 down to 5 or 6 H.P., perhaps as many air and gas engines, and a number of oil-testing machines; together with a sufficient number of steam-engine indicators, gauges and miscellaneous apparatus required to meet the needs of senior and junior classes numbering from 100

* "Les Laboratoires de Mécanique," *Revue Générale*, 1891.

† See Unwin's *Testing of Materials of Construction*.

to 125 men. Many graduate students and some undergraduates take up work in research, and the laboratory is thus rendered doubly productive. Professors engaged in their own investigations find the aid of such students very advantageous in matters of detail, and they often produce original work of real value. Besides the experience and training of the laboratory, the student secures often a still larger training by taking part in work conducted elsewhere, as in the testing of engines by the commercial branch of the establishment, and the investigation of efficiencies of the heating "plant" or of the water-supply and water-power machinery of the college. Such work as this, and especially such as is illustrated by the great investigations of Bauschinger and of Schroeter, of Wohler and Spangenberg, now universally familiar to the profession, is adding constantly and enormously to the store of facts and data upon which successful practice in construction depends.

These college laboratories now promise to supply such information more extensively and more systematically and with greater accuracy than can possibly any other means, with the possible exception of governmental laboratories like that at the Watertown Arsenal; which laboratories, however, rarely contain any large variety of apparatus or attempt more than a very limited range of work.* In them the colleges find their most visibly fruitful work and the student his most productive line of study; while the profession and the world are, through them, securing larger and more useful contributions to the sum of human knowledge than perhaps in any other way or field of work.

A NATIONAL UNIVERSITY naturally crowns and completes a system of national education. The States of the Union supply all the elements, or are rapidly coming to do so, of the primary and secondary education of the people. They are also all rapidly coming, through a generous and wholesome rivalry, to a common and high standard of education in every grade. There is thus nothing left for the Federal Government to do but to place at the head of and above the whole great educational system of our united system of States that greatest of universities, a National University, in which shall be collected the greatest men of the nation in their respective departments, to give instruction to the ablest students that the universities of the States may supply. Such an institution would

* See the annual Report of the Bureau of Ordnance, and its special reports on Tests of Materials, also annually issued, for an enormous mass of the most valuable statistics and data.

necessarily and appropriately be one mainly for the promotion of research in every branch of learning, and to give instruction to instructors in all departments of the pantology. Thus planned and thus conducted, with the wonderful resources of the General Government and all the great collections in science and in literature aggregated at the capital at its disposal, such an institution would magnificently complete the whole national pyramid, by giving it such an apex as the world has never yet gazed upon. This great scheme was first proposed by George Washington and his colleagues, a century ago, and was urged upon a busy and distracted people by Madison, Jefferson, and every other great political or official representative of the Government or of the nation, up to the times of Lincoln and of Grant, who were earnest in its favor. But the times were not ripe for it. To-day is the time for the harvest. The completion of the curriculum, by the introduction of the elements demanded for the "complete and perfect education" of the people, and the completion of the system of educational institutions of every grade from the lowest primary school to the national university in which are to be prepared the teachers of the teachers of the community, fittingly come together, and the complete and perfect educational system of a nation may now, for the first time, take form. It is two thousand years since, in the days of Hero, of Archimedes, of the disciples of Aristotle, and of Herodotus, and of Hypatia, that a first attempt was made to found a real and complete national university in which should be illustrated all phases of human knowledge, not excepting the at times despised applied sciences.

There has never, since the days of the Ptolemaic Museum, been a real university in existence. There is coming to be a hope that it may not be long before we shall see a second; and the fact that a strong committee of Congress has the matter in charge, and has reported favorably, backed by the indorsement of nearly every prominent educator in the country, as well as by generations of earlier educators and statesmen, gives that hope good foundation. As for facts: Governor Hoyt's reports, and especially his *Memorial* of 1892, and the documents and references there quoted, supply them in ample quantity. With the establishment of such an institution at the national capital, and the organization of those higher departments of technical and professional training, of education and research, which may be reasonably looked for in view of the advancing tendencies of the time, we may hope to see the best

possible safeguards established for our whole system of technical work.

According to our authority, the history of the movement begins with the very beginning of our history as a nation.

"The idea of a central university appears to have originated with Samuel Blodget in the military headquarters of General Washington, at Cambridge, in October, 1775. He suggested that when the war was ended amends should be made for the damage done to the colleges by the founding of a noble National University, at which the youth of all the world might be proud to receive instruction. The thought took a deep hold upon Washington, who declared the young dreamer a prophet, and expressed the opinion that his suggestion would one day be realized. From that time forth it was a living force in his mind. For it he made efforts in the Constitutional Convention; in his addresses and messages to Congress; in his correspondence with Jefferson, Hamilton, the District Commissioners, Governor Brooke of Virginia, and others; in his intercourse with the statesmen of his time, and in planning the final disposition of his estate.

"The nineteen acres now called the Observatory Grounds were selected and set apart by him, as President, in 1796. Indeed, for a long time that reservation was known as 'University Square.' As for the endowment, he desired to give fifty thousand dollars in shares of the Potomac and James River companies, then at par and believed to be of great value. He did give the Potomac shares, amounting to twenty-five thousand dollars. His stipulation was that the interest should be compounded, and if this had been done the total of Washington's endowment at this day would have exceeded four million dollars.*

"Thomas Jefferson was no less appreciative of the need of a great and national university than Washington. His message of December, 1806, as first draughted, stated the claims of the university cause

* "Unfortunately, George Washington's Potomac stock never paid but one dividend, and there was no pressure in those days towards educational appropriations from an ever-increasing surplus. The affairs of the Potomac Company were finally merged into the Chesapeake and Ohio Canal, which became a profitable enterprise, and endures to this day. What became of George Washington's 'consolidated stock' of that period, history does not record. Jared Sparks, Washington's biographer, thought the stock was 'held in trust' by the new company for the destined university."—*H. B. Adams.*

Washington's stock became worthless with the bankruptcy of the Potomac Co., and his good intentions failed of fruition, at least for the time.—*R. H. T.*

in terms so strong that Albert Gallatin, then Secretary of the Treasury, to whom it had been submitted for careful criticism, pointed out its apparent placing of the proposed institution before the necessary public improvements. Jefferson was not only ready to set apart public lands for a university endowment, but money from the surplus in the treasury. Like Washington, he asserted that it was better to leave to private enterprise the concerns to which it is equal, but he saw so clearly and broadly the impossibility of any private or denominational institution fulfilling all the offices of a national university that he pressed its establishment as an imperative duty of the Government. Madison was the champion of a national university from the beginning of his public career. He favored providing for it in the Constitution. As chairman of a committee of the House, he supported it in his report on a memorial offered by the Commissioners of the District of Columbia. As President of the United States, he thrice strongly recommended its establishment by Congress. John Adams also advocated the proposition in the convention, favored it in one of his messages, and often made it a theme of earnest discourse in social life. Presidents Monroe and John Quincy Adams were likewise friends of the university idea. Even President Jackson, less distinguished than some others for his love of learning, approved a twenty-five-thousand-dollar appropriation to Columbian College, on the theory that it was to grow into the proposed university; thoroughly believing, as he said, in 'the utility of a central literary establishment.' President Grant commended the subject to Congress in 1873, as, finally, did President Hayes in 1877 and 1878.

"Every head of the Smithsonian Institution has supported it, every head of the Geological Survey, every superintendent of the Coast Survey, and every Commissioner of Education. The foremost of our scientific men, like Henry, Baird, Bache, Agassiz, Peirce, Dana, Guyot, Gould, Mitchell, Hall, Barnard, Silliman, Newcomb, Langley, Goode, Hayden, Powell, Mendenhall, Billings, Ward, Gallaudet, and a host of other men of genius, with high aspirations for science and for the honor of the American name, have been its earnest friends. The American Association for the Advancement of Science expressed itself strongly as to the need of such an institution many years ago; and the National Educational Association not only unanimously indorsed the proposition, but agreed upon the plan now before the country, and created a permanent committee to carry forward the enterprise."

The fitness of the location comes not simply of the fact that Washington is the capital of the country, but largely from the essential fact that there are gathered at the capital such stores of wealth, in libraries, museums, scientific apparatus, and other needed portions of the equipment of a great university, as cannot by any possibility be brought together at any other point in the country. The principal of these collections are to be found in the following great departments of government:

In the Treasury Department of the United States:
- The Office of the Coast and Geodetic Survey.
- The Office of the Life-Saving Service.
- The Marine Hospital Service.
- The Bureau of Statistics.
- The Bureau of Engraving and Printing.

In the War Department:
- The Bureau of Engineering.
- The Bureau of Ordnance, and other military bureaus.

In the Navy Department:
- The Naval Observatory.
- The Office of the Nautical Almanac.
- The Hydrographic Office.
- The Bureau of Navigation.
- The Bureau of Yards and Docks.
- The Bureau of Ordnance.
- The Bureau of Construction and Repair.
- The Bureau of Steam Engineering.
- The Museum of Hygiene.
- The Bureau of Medicine and Surgery.
- The Dispensary.

In the Department of the Interior:
- The Patent Office.
- The Bureau of Education.
- The Office of the Geological Survey.
- The Census Office.

In the Department of Agriculture:
- The Botanical Division, with gardens and grounds.
- The Division of Vegetable Pathology.
- The Pomological Division.
- The Microscopical Division.
- The Chemical Division.

The Ornithological Division.
The Forestry Division.
The Entomological Division.
The Silk Section.
The Experimental Stations.
The Office of Statistics.
The Bureau of Animal Industry.
The Weather Bureau.
The Agricultural Museum.

Of establishments not under Departmental control:

The Smithsonian Institution.
The National Museum, with its twenty-two departments.
The Medical Museum.
The Medical Library.
The Bureau of Ethnology.
The Light-House Board.
The Commission of Fish and Fisheries.
The Arsenal.
The Congressional Library.
The United States Botanic Garden.
The Zoölogical Garden (in preparation).
The Government Printing Office.
The Soldiers' Home.
Office of the National Board of Health.
Government Hospital for the Insane.
The National Deaf-Mute College.
Courts: District, Circuit, and Supreme.

Of local institutions and establishments:

The Columbian University, with its professional departments, law and department of medicine.
The Howard University.
The Georgetown University.
The "National University" law school and school of medicine.
The Corcoran Art Gallery.
The Columbia Institution for the Deaf and Dumb.
The Columbia Hospital for Women.
The Children's Hospital.
The Providence Hospital.

Of learned associations of men:

The Philosophical Society of Washington.

The Anthropological Society.
The Biological Society.
The Chemical Society.
The Botanical Society.
The National Geographical Society.

To all of which may be added the National Academy of Sciences and the American Historical Society.

The total valuation of the collections, literary and scientific, belonging to the Government and available for purposes of instruction, is over $30,000,000; the aggregate expenditures for the care and use of them in the work of the Government are $4,000,000 annually, nearly.

The Smithsonian Institution, exchanging with every government, institution, and society of importance in the world, is prepared to offer extraordinary advantages in the departments of natural history and the arts.

There are at Washington, in all departments of the Government, "nearly a thousand experts in a great number of classes or branches of service, from the shops in the navy-yard to the Supreme Court itself; the whole body of them constituting the most important cluster of men of genius and rare attainments in the world. Hundreds of these men could serve a great university, either as lecturers and instructors, or by furtherance of its scientific work in some other way; thus greatly aiding it, while also adding something to their very moderate regular incomes, and gaining new inspiration for a still better service in their usual rounds, if not, indeed, for the supreme work of new discovery. For a great and powerful nation to allow all these vast and varied resources to remain indefinitely without the fullest possible use in the interest of science and learning, while at the same time multitudes of its citizens are suffering irreparable loss for want of them, is incomprehensible. It is certainly the worst economy conceivable, and seems hardly less than criminal."

Dr. Dollinger, in an address, some years ago, before the Munich Academy of Science, remarked that, in his opinion, "the main hindrance to literary and scientific progress in the United States is the want of a great central university." He thought that the perfection of a system of educational centres and institutions, having a common plan and being parts of a common organism, each doing its share and doing it well, would prove to be the only efficient

method of education of the people. Says Dr. B. A. Gould, in his Phi Beta Kappa address of 1856, in his always well-chosen language and eloquent speech:

"An intellectual centre for a land is a heart, but subject to no induration; it is a brain, but liable to no paralysis; an electric battery which cannot be consumed; it is a sun without eclipse, a fountain that will know no drought. To such a university our colleges would look for succor in their need, for counsel in their doubt, for sympathy in their weal or woe. There is no one of them but would develop to new strength and beauty under its genial emanations; none so highly favored or so great that its resources and powers would not expand; none too lowly to imbibe the vitalizing, animating influences which it would diffuse like perfume.

. . . . . .

"We want no university keeping up with the times and commending itself to the public approval. We want one which shall be just as far ahead of the age as is consistent with being within hail; which shall enlarge and expand the mind and taste and appreciation of the public, compelling the admiration of the public, not soliciting its approval. We want a university which, instead of complying with the demands of the age, shall create, develop, and satisfy new and unheard-of requisitions and aspirations—which, so far from adapting itself to the community, shall mould that community unto itself; and which through every change and every progress shall still be far in advance of the body social, guiding it, leading it, urging it, drawing it, pulling it, hauling it onward.

. . . . . .

"The university will contain a soul, a restless, striving, throbbing, impelling, shaping, creative vitality; and will become, not an Italian, nor a French, nor an English, nor a Spanish, nor a German, but preëminently an American university—glowing with American fire, pulsating with American aspirations, and, strange as the words may sound to us to-day, radiating with what will then be American scholarship, American depth of thought, American thoroughness of research, American loftiness of generalization. . . . It will bring the refining power of ancient lore and classic elegance to balance and counteract the all-pervading tendency to mere material science; it will leaven the tone of thought throughout the world by introducing the precision of exact science where the vagueness and confusion of the schoolmen have long reigned; it will lift the philosophical and philological sciences to a far higher

scope and standard as specialties, while it unfetters the struggling mind from the incubus of an antiquity which recognizes no progress, a conservatism which excludes all things which are or ever have been new. For I assure you that there never existed a university which surrendered either to conservatism or radicalism; never a university which was not eminently nationalizing in its tendency. . . . Under the most absolute despotisms the universities have been vantages which flow from the concentrated accumulation of a whole nation's genius and talent. . . . There is no substitute for the 'encounter of the wise.' Like that of flint and steel, it strikes out without cessation the glowing sparks of truth; like that of acid and alkali, it forms new, unexpected, and priceless combinations; like the multiplication of rods in the fagot, it gives new strength to all, while taking it from none. A spiritual stimulus pervades the very atmosphere electrified by the proximity of congregated genius, its unseen but ever active energy—floating in the air, whispering in the breeze, vibrating in the nerves, thrilling in the heart—prompts to new effort and loftier aspiration through every avenue which can give access to the soul of man."

Says Dr. Herbert B. Adams:

"Washington's dream of a great university, rising grandly upon the Maryland bank of the Potomac, has remained a dream for more than a century. But there is nothing more real or persistent than the dreams of great men, whether statesmen like Baron von Stein, or poets like Dante and Petrarch, or prophets like Savonarola, or thinkers like St. Thomas Aquinas, the Fathers of the Church and of Greek philosophy. States are overthrown, literatures are lost, temples are destroyed, systems of thought are shattered to pieces like the statues of Phidias; but somehow truth and beauty, art and architecture, forms of poetry, ideals of liberty and government, of sound learning and of the education of youth, these immortal dreams are revived from age to age and take concrete shape before the very eyes of successive generations."

DISCUSSION.

Mr. Wm. Kent.—I think this Society is to be congratulated that it has in Professor Thurston a man who can take a broader view of the whole subject of education than is usually taken by engineers. His expanse of view extends from prehistoric times down to the present, and not only that, but it reaches far into the future, and I am heartily glad that we are to have in the

Transactions such a memoir as he has given us. We are very apt, from being connected with technical schools, to have our minds get into the rut in which these schools are apt to put us, and to neglect the broader view of education in general which Professor Thurston has opened up. The technical schools of this country are in admirable condition. Whatever defects they may have are being gradually remedied. In other branches of education, though, the situation is not so promising, and I hope that educators will open their eyes to the existing defects. Our technical schools of the textile industries and of the art industries have scarcely yet existed. There is not the same opportunity given in this land for a boy to grow up to be an artist or an expert in textiles as there is for him to become an engineer in a machine shop. Another defect in our educational system is the intermediate education between the primary school and the professional school. What shall we do with the boy between the ages of thirteen and seventeen? I think that is an unsolved problem to-day. There is no harmony of opinion about it. We need some discussion of that whole subject. This is one of the gaps left in our educational system. To-day not enough attention is being paid to the question of, What education shall you give a boy between thirteen and seventeen? And that question may be divided into two parts, namely, What education shall be given to that boy if he is expected to develop into a professional man? and, What shall be that education if his school-life shall be cut off at seventeen? Certainly the answer to the question will differ according to what is going to happen after he reaches that age. Now, as to manual training, I have been gratified to learn how graduates and teachers of the school at St. Louis state that if you take two boys, say at twelve or thirteen years of age, and put one through the manual training school as a preliminary course and put the other through the academic course, the one who has gone through the manual training course develops better intellectually and has a better chance of succeeding in the university course than the other. It is a most noteworthy fact, if that is true. Why is it so? It may be that at these early ages the average boy is not able to give more than three or four hours a day to actual mental effort, and if you give him two or three hours a day of manual training you do not subtract that time from the time which would be otherwise devoted to training the mind, but you subtract it only from that

time in which the mind is dormant. Professor Thurston has quoted from Professor Dwelshauvers-Dery, in regard to what causes the difference between the slowness of Europe and the rapidity of America. I would like to take exception to what Professor Dwelshauvers says there, and to say that what he refers to is only one narrow branch of American experience. In his view at the Paris Exposition he saw how the Americans were ahead in machine tools, and Professor Reuleaux at the Centennial Exhibition got the same idea, but recently Germany has crowded us pretty hard in this direction. America cannot claim preëminence in all branches. In steam engineering we have developed the Corliss engine. Perhaps we have developed the little short-stroke engine that we are trying so hard to get rid of now. But what has America done but copy after Europe, in the way of heavy forges? The Bethlehem and the Carnegie works only within the last two years are doing the work which has been done in Europe for many years. What America has done in heavy iron and steel work, as in armor plate, Europe has been doing for twenty years. In marine engineering we are but following England. In iron and steel manufacture we now lead the world, but where would we be in steel metallurgy but for Bessemer, Siemens, Martin, and Thomas?

Now, I will close by saying that I am exceedingly gratified that Professor Thurston has presented such a strong argument in favor of a National University at Washington. The first President of these United States was a century in advance of his age when he proposed it. We need that university in the worst way; we ought to have facilities for establishing it, and all it wants is a vote by Congress that it shall be established.

Mr. H. F. J. Porter.—There is one other point of view from which we ought to look upon the technical education of to-day. We should consider the effect which present methods of teaching are having upon the standing of the profession before the public, since it is the latter to whom the profession is indebted for its livelihood. There is no doubt in my mind that our educational institutions are doing well individually, but something more than that is wanted. It is necessary that they should act together, in order that the public may be satisfied with what they offer to it.

Each institution is in reality a factory turning out engineers;

but so long as one turns out some who differ in qualifications from those turned out by the others, provided that each is not branded with the name of his *Alma Mater*, the public has no way of becoming informed in regard to what a man, calling himself an engineer, really amounts to. Confidence in the profession under these circumstances cannot be maintained, and consequently its reputation suffers. To my mind it is necessary, both for the good of the profession and for public safety, not only that a high grade but also that the same grade of men should be turned out from all the technical schools. It seems to me that if we can obtain a uniform system of educating engineers we will have made a long step towards raising the status of the engineering profession. In this connection I have just been informed by one of our most able professors of engineering, who is with us at our congress, that he is now interested in an effort which is being made to form an organization of technical educators. I feel that this move is in the right direction and will lead to the adoption of more uniform methods of teaching, and I hope that every engineer in our land will encourage it and lend his aid toward the establishment of a recognized standard of excellence which must be attained by every technical student before he will be allowed to proclaim himself to the public as a practising engineer.

We have heard a great deal of complaint in the press and elsewhere within the last few years regarding the present status of the engineering profession, and there has been quite a little talk of how engineers have been treated generally, and more particularly of late at the Exposition. Now, as I am an official of the latter, and have been in a position to know something about the situation there, I want to say a word about it to you as members of my own profession. In the first place, it must be acknowledged that the people who have had to treat with the business ends of that enterprise are at least capable men. When they had to deal with the engineering profession they used the same methods as they did with everybody else; they looked around to get their money's worth, and they got it and more too. Perhaps they could have gotten the same thing by dealing with the profession in some other way, and they might perhaps have obtained better results; but when they needed engineering ability they found the profession in a disorganized condition, and they simply hunted about and got the best

material they could at the lowest possible rates. They had no time to request the profession to organize itself for self-protection, and they had no business inclination to do so if there had been time. I assure you, however, that they did not obtain the architectural ability they needed in the same manner. They found that they had to deal there with an organized body, and that they had to treat with the architect very differently from the way they could with the engineer. Now, I do not think it is fair to throw any blame upon the Exposition authorities because they treated with the engineer as they did. It was rather the fault of the engineering profession that it was not in a condition to be treated with properly. And this condition will last as long as the public knows that engineers are not educated alike, and as long as it cannot discriminate between those who are thoroughly capable and have had experience, and those who have had no practice whatever, and as long as it knows that there is no restriction upon any one's assuming the title "engineer" and entering the field for practice.

The Canadian Society of Civil Engineers is coming to the front in this issue. They have appointed a committee to confer with other engineering bodies in Canada and the United States and report this fall as to the advisability of having the Canadian Society of Civil Engineers authorized and empowered by law to confer the title of "engineer." In other words, no matter what titles may be given to graduates by educational institutions of that country, they will not be recognized among engineers unless they have received a license to practise from the Canadian Society of Civil Engineers.

It seems to me that it would be very proper for this Society in its Council to consider that same subject and appoint a committee to confer with the Canadian Society for the purpose of discussing the question.

It could confer also with our sister engineering societies and with the newly forming organization of technical educators, and any other body which has an interest in such matters. Now, with that end in view, I offer the following resolution:

Resolved, That the Council of the American Society of Mechanical Engineers consider the advisability of recommending to educational institutions a uniform system of technical education, and that it endeavor, in connection with the American Society of Civil Engineers, American Institute of Mining Engineers, the American Institute of Electrical Engineers, and the Canadian Society of Civil

Engineers, and such other organizations as may seem to be proper, to carry out such a uniform system as is deemed desirable.

Also, *Resolved*, That the Council consider the advisability of recommending that technical institutions give the degree of Bachelor of Engineering only, and of establishing a body which would have the authority by law to give the final title of "Engineer," and that it endeavor, in connection with the above-mentioned societies, to carry out such a programme.

The National University so ably advocated by Professor Thurston would be the proper authority to act through its various State branches in giving the final title, and I hope that such an institution will be established.

Mr. J. Wendell Cole.—I am very thankful for the paper which Professor Thurston has presented. I had friends who were educated in the old style, who seemed to think that because I had no taste for Latin I did not want an education, and the result was that the only way I found to start first was to go into the machine shop, and then as soon as I found that I needed light, look for it. Bringing up the two boys that I have, I educated one who has graduated mechanical engineer, and the other is at college, the second year of the same course. I am endeavoring to give them the advantage of what I learned through my disadvantages. When a boy graduates he has just built a grand foundation. The technical education is a firm foundation on which practice and experience may build a magnificent superstructure. I have also found that if a person does not follow the branch of engineering, the result of a thorough engineering training should be to educate the brain to accept only accurate data and always require precision of execution in any walk of life in which the graduate is called upon to do his work; and I think it will be found that graduated engineers are doing that, whether they are following the engineering profession or not.

Those of us who are more in commercial life should feel thankful to these gentlemen for holding fast to their issue of training the young and educating our boys.

Mr. Chas. H. Manning.—I have enjoyed reading Professor Thurston's article very much indeed, but on the sixty-ninth page I think he omitted one item that has borne very strongly on the education especially of steam engineers in the last two decades. In 1871, and for some ten or eleven years subsequent to that, there was a class of cadet engineers admitted to the Naval Academy each year, of about twenty-five members, to be educated especially for the engineer corps of the navy. The instructors were men

drawn from the engineer corps, men of ordinary ability and none of great attainments, but they were men with a purpose and men thoroughly interested in the work they were doing. The results of that work, I think, are plainly visible to-day in very many of the engineering schools of the country. There are five or six of the graduates under that system now occupying professors' chairs and with great credit to themselves. The success of the machinery of the new navy and the success of the construction corps are partly traceable to the effects of that school. And I think it is a matter of very great regret that that school was allowed to go under from the force of circumstances.

Mr. W. F. Durfee.—It seems to me that one of the gravest difficulties that the engineering schools of the country are laboring under is the impression which seems to pervade them all, that, given a boy of reasonable intelligence and fair preliminary education, and money enough to pay his tuition, he can be graduated as an engineer after being in such a school for three or four years. It would be an exceedingly absurd thing, as we all know, if any one should deliberately propose to graduate poets. The poets are born, not made. The material for the poet has got to be there before the education can be successfully applied. Just so you have got to capture your engineer before you attempt to educate him. Some of the worst engineering failures I ever knew of were perpetrated by men of fifty or sixty years of age, one of whom I have in mind now who was graduated first of his class from a leading university, and afterwards was at the head of his class in West Point, and who subsequently served for a long time in the United States Engineers Corps; and I have no doubt that everybody here can recall similar instances of incompetency in men who lacked, not education, but a knowledge of the eternal fitness and adaptation of things, and of the proper means to use to accomplish desired ends. They had no idea of the practical side of the profession. They could do anything and everything in the way of mathematics. What we want in our engineering schools is a decision something like this: I remember a student, forty years ago, who got into some difficulty in college and was expelled. It had become evident to his preceptors that he was not going to be an engineer. He went to his professor and said: "Professor, don't you suppose the faculty would let me stay here if I would promise to behave myself?" "Yes." "Well," he said, "I will go and see the presi-

dent at once." "Well," said the professor, "if they do consent to keep you, I shall immediately write for your father to come and take you home." So the young man concluded that he might as well go without seeing the faculty. Now, that is the kind of natural selection that should be exercised by the managers of the technical schools of the country. My idea is that after a boy has been connected with a technical school for six months or a year, it ought to become evident to the heads of the institution whether he has in him the kind of sense that will make an engineer. He may be very well qualified for a doctor or a lawyer, and yet be utterly incompetent for an engineer. I think the proper selection of men for the engineering profession has been very much neglected. It is perhaps difficult to carry it out, but I think with proper determination it is quite within the limits of possibility.

Prof. Geo. I. Alden.—Regarding the motion to refer this matter to the Council of this Society, I think that is a very proper step, although I cannot see how the whole of it can be accomplished. I think it has one feature that is good, and that is that the schools that are preparing young men for the engineering profession should graduate them as Bachelors of Science in engineering, or, if you please, Bachelors of Science in mechanical engineering, and then if they could establish some way, either by a system of post-graduate education which should have supervision from some central source, or by some committee which should be appointed under this motion from the various States, then the young men might, after having graduated as Bachelors of Science in engineering, receive their titles as mechanical engineers. That is, if a young man should show that he had in him that which is necessary to make an engineer, then he could get his professional title as a mechanical engineer. I think if that could be done, then the schools of engineering which now have nothing to control them—but, as has been shown, one school is working in one line and another school in another line—these schools would see what process of evolution was best adapted to bring out the best system for this purpose. I think it is fortunate that the different schools can pursue their different methods, but perhaps they need a certain standard toward which to work. That feature would enable us to understand better what the graduating degree means, for then we should say, "This young man has a degree of Bachelor of Sci-

ence in engineering from the Massachusetts School of Technology, or from Cornell University, or from Purdue, or from Stevens Institute," and then we should know his grade and how to esteem him. That suggestion in the motion struck me very favorably.

The Chairman.—Gentlemen, are you ready for the motion? All in favor of the resolutions will say Ay; opposed, No.

(Adopted.)

*Professor Goodman.**—I would like to make a few remarks as coming from England. In the United States it appears to me that the money that has been appropriated by the States for technical education has been used to much better advantage than it has in England, and I think it is largely due to that fact that engineers are more favorably disposed towards your graduates than towards ours. In England we are in the unfortunate position of having our schools managed by men who know as much about technical education as the man in the moon, and they spend large sums in educating up to a very low standard very large numbers of students. The trouble has been that we have only second and third rate teachers, and the money has been spent in giving every street urchin just the merest smattering on one or two scientific subjects. Now, it appears to me that in the States what you have aimed at is educating a few students up to a high pitch of perfection, rather than a great number up to a low pitch of perfection. On account of the advantages of your system we find that engineers are very much more ready to take graduates into their works than with us. Various speakers have spoken of the advisability of all colleges adopting the same course of construction. I think that might be more easily carried out here than in England. The fact is that at the present day in England there are no two professors agreeing as to what should be taught. One will have it that nothing but manual training should be taught; another, that nothing but scientific training should be taught; another, that it is useless to have a laboratory; another, that drawing ought not to be taught, and so on. So with us it would be absolutely impossible at present to get our engineering professors to agree on any one course. We hope in the course of a few years that a more general course of training will be adopted, as being

* Of Leeds, England.

more beneficial to the student than the narrow course. It is a disputed point with us whether manual training should be given in a college or not. For my own part, I should say that every student ought to have manual training, but I do think it ought to be kept separate from the college. It should be given in a technical school, and the scientific training should be given in the university. So far as the English system is concerned, the combination of the two has not been successful. Those who have done one or the other thoroughly have succeeded fairly well, but the institution that combined the two has certainly not succeeded so well. In the Yorkshire College school, with which I am connected, we do no manual training whatever. The whole of our course for three years is the applied sciences course. We have the finest equipment in our laboratory in the land, and we can easily keep our students for two days a week on a series of experiments which proves most valuable to them in after-life. We have more applicants than we can possibly take in to-day, and we are just at the present time putting on a new entrance examination, and as far as possible reducing the number of students who have not had manual training, either in a technical school or in works, and we very much prefer having students of nineteen or twenty years of age who have spent two or three years in work than to have those who are fresh from school. In our course we do exactly as the last speaker said, we simply give them the Bachelor of Science degree. We go on the idea that we cannot possibly say that a man is a qualified engineer who has only gone through a college. We give him the Bachelor of Science degree to show what scientific training he has had, and then his diploma showing he is competent to become a member either of a society of mechanical or of civil engineers.

President E. B. Coxe.—From my experience with engineers, I would say that the most important point of their education is that relating to the principles of physical science. A man who has been thoroughly taught the elements of mathematics, physics, and chemistry, and who has a good knowledge of draughting, although he need not be a good draughtsman, will succeed better as a civil, mining, or mechanical engineer, than one who lacks such fundamental training and has had an immense amount of instruction in the details of the profession he intends to adopt. Such knowledge of details can easily be acquired in

practice, providing a man is capable of becoming a good engineer. In many cases, I am sorry to say, these elements are neglected for more advanced studies. With the engineer as with the engineering structure, nothing will replace a good foundation. Some of the best and most successful engineers that I have known have had such fundamental training, and have succeeded admirably in a branch of the profession which they never intended to adopt, and for which they were not trained in college.

*Professor Thurston.**—I think that gentlemen interested in this matter, but unfamiliar with the practice of the schools, if they investigate the subject, will find that the most important part of the work of all successful schools throughout the world is, first of all, that of turning out from the great stream of humanity coming to them those evidently not qualified to enter the profession. Nevertheless, many students enter our school who are not well fitted for the profession. You will often find that in a good school ten per cent. of all the students are dropped out at a single "sifting," and in many cases you will find that one-half of all who enter is thought a small percentage of mortality; two-thirds is not an uncommon loss.

Another very important matter should be remembered; all engineering schools engaged in giving instruction in mechanical engineering have manual training shops attached. And it should be understood that the manual training of these shops is not simply a training in the use of tools; it also educates the brain. At St. Louis the man who has gone through the manual training school has been shown to be a more successful student than the one who has not been so qualified.

Another point to which I have not alluded in this paper is yet of enormous importance, and I desire to say a word in regard to it here; especially as there are present many men greatly interested in this work. It will be observed that the independent universities, colleges, and schools are having continually harder and harder times. The State universities, on the other hand, as a rule are enjoying better times, especially in the West. The reason for this difference is not competition, but the fact that in many schools the operating expenses must be defrayed by tuition fees, while in many other schools the income derived from invest-

*Author's Closure, under the Rules.

ments has supported them, and still others are supported by the State. The Rensselaer Polytechnic Institute, for instance, is supported almost entirely by tuition fees. The Eastern universities are mainly supported by invested capital; but, during the last few years, the rate of income on investments has been steadily decreasing, and it is very certain that it must go on decreasing; and that those institutions which are now dependent upon income from invested capital must expect to see their financial support slipping away from them, and those dependent upon tuition fees are finding the rivalry of other schools reducing the rates. It finally comes to this: that the States must ultimately be looked to, to support all classes of schools, if all classes are to succeed. That is a phase of change that we now plainly see going on. It is thus necessary that every one, who has any power in this matter, should do what he can to secure stronger support for schools depending upon tuition fees, and in other cases endeavor to find a way to interest the legislatures of the States and to secure from them that effective and permanent support without which our whole great technical system of education must eventually fall. This seems to me the most serious cloud upon the outlook for popular and technical education in the future. Education is becoming more and more costly, and the difficulties in the way of supplying it are of the gravest. It costs at least $300 a year to instruct each student, while the tuition fees are usually low, and rarely exceed $200 in any case. Those who have sufficient interest and sufficient breadth of view to see what must be done for the future may look to this as being a line on which they may do especially helpful work, if they can accomplish anything at all.

DXLIV.*

HAULAGE BY HORSES.

BY THOMAS H. BRIGG, BRADFORD, ENGLAND.

WHILE steam and electricity have been doing much in the recent past to quicken transportation, the conditions affecting haulage by horses have been entirely neglected. The mechanical engineer has sought to remove every hindrance to the speed and economy of the locomotive, with the result that it now makes one hundred miles an hour as easily as it did twenty-five a half-century ago. The steam-horse has shortened the haul for the living horse, but has improved it in no other respect. Electricity is relieving the horse to the extent of taking his place as a motive power on street cars, as a result of the extravagant demands made upon his energy. In reality this is no relief, since he is crowded into worse drudgery, and all because he is so unreasonably handicapped.

Man is continually devising methods to lighten his own labors, and the present age is characterized by inventions calculated to substitute the forces of nature for the strength of man. But the horse is required to bear his burdens and haul his loads under the same disadvantages that have hampered him in the past. Horses may think, but they cannot speak. If they realize that they are working at a disadvantage, they are unable to tell us so, and they continue to suffer and waste their energies—the patient servants of a thoughtless and unconsciously cruel master.

It is to man's interest that his best friend in the brute world should be strong, live a long life, and waste none of his vital force. Much attention has been given to the development of breed in horses, and the result is a vast improvement in their strength, speed, and beauty. But while we have been developing horses that are capable of doing better work we still handicap them by the unscientific methods under which we require them to labor, and there is an absolute loss, in many cases, of 50% of their strength. This is not guess-work. The fact is capable of practical and scien-

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

tific demonstration. It is surprising that the disadvantages under which a horse labors should not have engaged the attention of scientific men long ago.

The manual training schools of this and of every other country teach all the arts from needlework to blacksmithing. There are schools for farming and all the professions. But there is not so much as a text-book on wagon and carriage building. If a boy becomes a wagon-maker, he makes no study of the economical application of force to move it. He cuts his lumber and welds his iron after the old methods, except as he may modify them to suit his taste in style. If the horse can be hitched to the vehicle in a manner which will lighten his load, the maker of the vehicle does not know it.

In the simple matter of so hitching a horse to a wagon as to lighten his load we encounter scientific problems based on scientific principles, and yet almost everybody treats the subject as one of common character. We have in England large and old-established wagon-making firms that never knew what it was to work to a scale drawing. What would the world think of an engineering firm that worked on such a basis?

I am sorry to say that in all my experience I have never met a wagon or a carriage builder who had an intelligent conception of the fundamental principles of economical haulage. The builders rely, sad to say, too much upon the users of vehicles. The latter very naturally come with conflicting statements, and well they may, because of the many different conditions under which they work their vehicles. At present it seems to make no difference to the coach-builder whether the particular vehicle he is making is to be used in a hilly or a flat country. The fact is, he does not know that there is a difference, or at least what that difference is.

There are all sorts of conflicting notions upon the theory of long and short wheel-based carriages, and very different results are obtained from long and short vehicles, but nobody seems to know exactly why. In fact, there is nothing but chaos as between the ideas of theorists and practical men. From what I gather, the coach-builders owe their advancement to coachmen, and the latter, for want of scientific knowledge, or a knowledge of facts, have had to work largely in the dark. Of necessity they were compelled to act upon a knowledge of what they saw, and not upon scientific principles. The driver finds that a particular angle of trace is better or worse than another, taking the whole day's work into

consideration; but if he goes into another part of the country he probably finds that the angle should be varied. He learns by observation that it is better or worse for the horse if a two-wheeled cart is loaded in different ways, according to the circumstances. He is correct in his conclusions, and yet engineers say that "to transport a given load over a given distance in a given time, the work done in foot pounds is just the same." These engineers differ from the driver; nevertheless, the engineers are wrong and the driver is right, so far as the understanding of the latter goes. In spite of what engineers have often said upon the question of "work done," I resolutely maintain that the work done in *pushing* a wheelbarrow, with a given load over a given distance, is *not near* so great as when the same vehicle is *pulled*.

Again, we have men of supposed scientific information who build hand-carts to be hauled by costermongers. We would not like to admit that these men know more about the principles of mechanics than we do; and yet they very correctly refuse to haul their carts by the handles. These men know no more about the principles of mechanics than the carts they haul, but they must be credited with knowing which method of hauling is easiest for them. I have made it my pleasing duty to investigate their practices, and when I have come to plot out all the forces exerted by them, as well as by nurse-girls with their perambulators and by boys with their go-carts, I have found that nearly all of them were acting in perfect harmony with natural law and common sense. But we, who boast of our scientific knowledge and of our humanity, in yoking our horses to their loads act in direct opposition to natural law and common sense. No costermonger would suffer himself to work under such conditions as we ignominiously impose upon our horses. Surely, in this respect, what is good for man is good for beast.

As I have already stated, I am convinced that fifty per cent. of the energy of a horse is wasted by the unscientific method of attaching him to the vehicle which he is required to haul. I was led to the investigation of this subject by a very simple incident, as Isaac Newton was led to the discovery of the law of gravitation, if I may be pardoned the reference, by noting the fall of an apple to the ground. Two horses were being cruelly beaten by their driver in the streets of London, because they had great difficulty in moving their load, which, under ordinary conditions, they could have moved without much effort. Observing the conditions, I stopped and asked myself the question, from a mechanical point of

view: "Are the horses attached to the load in a manner which will give them the greatest possible control over it?" I at once answered my question in the negative. "No, they are not, because they are relying almost entirely upon their own unaided weight for the force they can exert, and they are unable, by reason of the direction of their traces, to exert anything like their full natural strength."

Let me illustrate by an example. *A* is a windlass placed on a smooth floor. The hauling rope is passed under pulley *B* and over that of *C*, and attached to a heavy weight, *W*—not forgetting that the windlass is resting on a smooth surface, neither pinned nor weighed down. The weight *W* being heavy and the road smooth, the most natural thing in the world to expect would be that the windlass would slip, or slide, toward the weight.

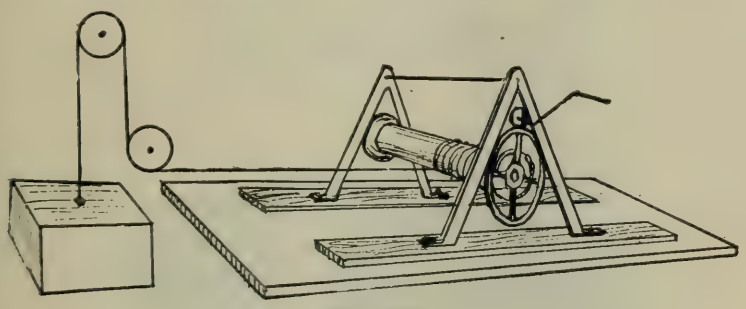


FIG. 326.

What would you think of the man who would thereupon pick up a sledge-hammer and smash the machine because it would not haul the load? Would you not look upon him as possessing less than normal sense? I am sure you would. But this represents, as nearly as possible, what was being done with the poor horses referred to, and what is being done daily to thousands of others. The unfortunate brutes were being whipped because the load had a greater mechanical advantage than they had, and through no fault of theirs; it was the fault of the world's imperfect knowledge of animal mechanics, or of "cause and effect." The horses were unduly and wastefully straining every nerve, because they had not sufficient weight to give them grip to start their load, and the method of attachment was such that they could not get the grip. "They would if they could, but, poor brutes, they can't."

Let me give a further illustration of my meaning. If we attach

an elephant to a large van in such a manner as we attach our horses, the load and the gradient might be such that he could not possibly haul it. But, if we rid him of the fettered system, and permit him to perform his task as instinct and common sense dictate, both to man and beast, he will go behind the load where he can place his trunk beneath the van and lift considerable weight. Besides, he will thrust with his head, as depicted in the sketch

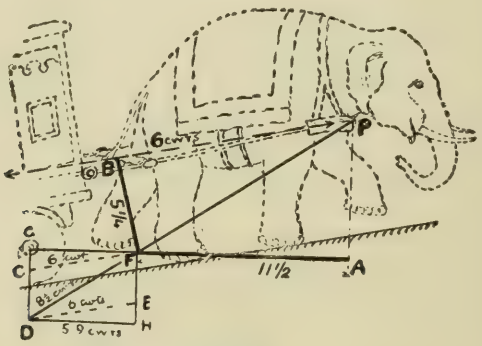
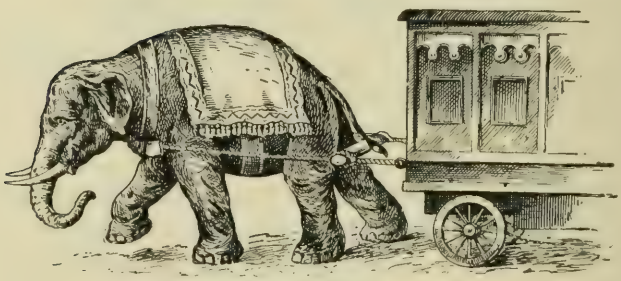


FIG. 327.



From which diagram Fig. 327 is made.

before you. He would manage *better* in *front* if he could only secure the lift at the vehicle.

If you plot out the forces in the two cases you will observe that, when yoked like a horse, the more the elephant pulls the more weight he takes from his fore legs and transfers it to his hind legs. Therefore, we find ultimately when he is thus exerting his maximum effort the whole of it is measured by the strength of the hind legs alone. On the other hand, if he applies his forces as he thinks best, he can not only exert all the muscular power of his hind legs, but also that of the fore legs. Surely no one will doubt his power

to exert a much greater force by the combined efforts of four legs than of two. To deny this, one must contend that a man can bear as much weight upon his back when standing on one leg as when standing on both.

It is manifestly impossible for a man to lift so great a weight when it is placed on one side of his body as he could if the weight were centrally under or over him, because, when lifting to his ut-

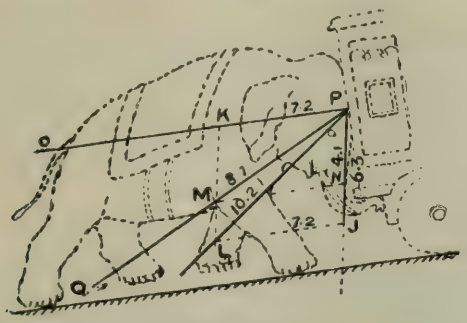
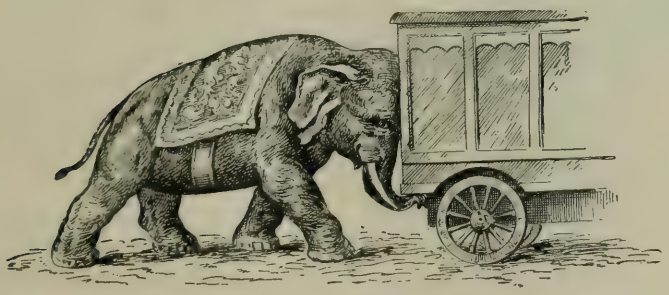


Fig. 328.



From which diagram Fig. 328 is made.

most, he must of necessity support not only all his own weight on the *one leg* nearest the load, but, in addition, he must support the total weight he is lifting.

Notwithstanding the apparent simplicity of the question of haulage by horses, it must be approached by scientific methods. The underlying principles are as real as the principle of gravitation itself, but they must be uncovered by those who are able to analyze forces and trace their resultants. The solution of the question belongs to the engineer, and, as already stated, the public will look to him for guidance in a matter of so much commercial as well as scientific importance.

What is a horse, and why can he pull a greater load at one time than at another? A horse is simply a living machine. He has the power to transport himself from place to place at will, or at the command of his master. A machine of iron or steel, like the locomotive, has power to move only by the application of steam or electricity, under the guidance of man. Its power to pull or haul loads is determined by the conditions under which it is placed and the amount of energy it possesses. For example, a heavy load may be lifted by the common windlass, if the pull is vertically upward. But, if the load be so shifted that the pull is horizontal instead of vertical, as in Fig. 326, the machine must be fastened to the ground or weighted to prevent its slipping. It is so evident that its power is weakened by the direction of draught, that the question does not need further discussion.

The principle is the same when applied to the horse, and it is easy even for the unscientific mind to see that the angle of the trace may be such that the animal could not pull a pound beyond his normal weight unless held to the ground by some force or added weight, the alternative being that he would be "lifted from his fore feet."

Again, if the machine, whether it be in the form of a man, horse, or inanimate structure, should be placed upon ice, the coefficient of friction would be very small. If it should require only one pound horizontal pull to overcome the friction due to the weight of the man on the ice, his limit of haulage would be one pound through a similar trace. If ten pounds would overcome the friction of the horse on ice, then the horse, however powerful he might be, could effect only a ten-pound draught. The same rule applies to every condition of road. By this we can readily understand why horses cannot haul the same load upon one road as easily as upon another, and why it is more difficult to pull a load up a hill than along the level. Surely it must be clear that neither a horse nor any inanimate structure would require so much force to pull it *down* an incline as on the level or up hill.

The amount of resistance which a horse can overcome depends upon the following conditions: (1) his own weight; (2) his grip; (3) his height and length; (4) direction of trace; (5) his muscular development, which determines the power to straighten the bent lever represented by his body and hind legs against the two resistances, the vehicle through the trace attached to the shoulder and the hind feet against the ground.

Many erroneous notions exist among men as to the best inclination of the trace for the horse. For instance, if a horse can haul a given load up a given hill with a deep inclination of trace, and cannot do so with a horizontal one, it is generally thought that the former is the better angle. It is, indeed, for that particular hill, but immediately the hill is surmounted it becomes a very bad angle, inasmuch as it involves a great loss of power, as I shall endeavor to prove conclusively.

To pull through a very low trace, or to have a man, or even two or three men, on a horse's back, is advisable and even necessary if a horse is expected to haul a load requiring the full force of his muscles at any particular moment—and for the moment, under such conditions, he would be able to draw a much greater load than

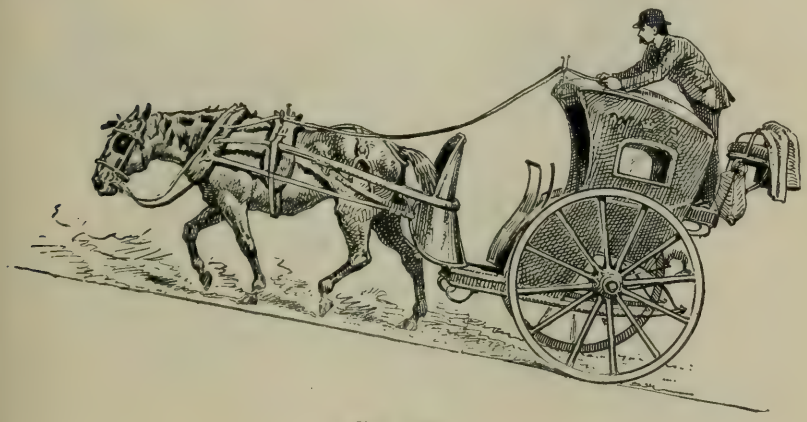


Fig. 329.

without the added weight. But any person can see that the animal could not travel far with any vehicle if he must carry three men on his back in addition to hauling his load.

This point may be illustrated by the hansom cab. When the horse is pulling up a heavy gradient, the driver is often seen to lean forward, thus endeavoring to throw additional weight on the horse's back, knowing from experience that the animal can get along more easily if he carries some of the weight on his back rather than all of it on the wheels. If the driver should care to alight from his box and mount the horse, a very great benefit would be conferred during a heavy pull. If the gradient be a slight one and the road a good one, it would be better for the horse if the

man were to keep his seat and not even lean forward at all, but rather backward. Therefore, to deal justly with our horses, we should not only study cause and effect, but should devise some means by which, automatically, every possible advantage could be given to the horse at all times. Otherwise, there must be a constant waste of energy, tiring the horse prematurely and increasing the chances of his stumbling and falling. It is easy to understand that the efficiency of the horse is lessened and his life shortened if he is continually bearing an unnecessary burden.

I wish now to point out the importance of taking into consideration all the forces which produce a certain effect when the load

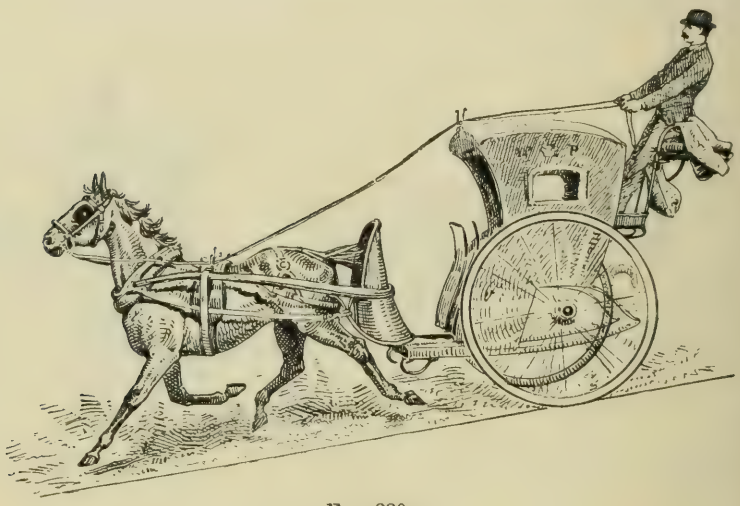


Fig. 330.

is placed in the rear or in the front of the axle. Let us first consider the conditions and the results when the load is placed at the rear end of the cart, as in Fig. 331.

I will omit to plot out the simple levers constituted by the cart itself and the axle as its fulcrum. We will assume that the said lever will produce such a lift at the belly-band as to equal ten pounds at the point A or T. The lift at the belly-band must therefore be greater than ten pounds, because the long arm of the lever from the centre of the wheel to Y (point of backband) is shorter than to the point of the hame A. We must now understand what it is that the horse is doing. We know that if both the traces should break the load would run backward down hill. But,

as the load is kept moving forward up the hill in spite of its tendency to run backward in obedience to the force of gravitation, we know that a counteracting force must be exerted by the horse through the traces. Inasmuch as we are also aware that the cart would tilt upward at the shafts, were it not for the influence of the belly-band, it must be clear that the horse is exerting a force not necessary to the mere pulling of the cart. He is holding down the shafts with a force at the belly-band equal to ten pounds at *A*.

Now let us suppose that he is exerting a force of 36 lbs. through *AB* in a line from the hame to the centre of the wheel. Then let *AC* represent the vertical depression necessary to hold

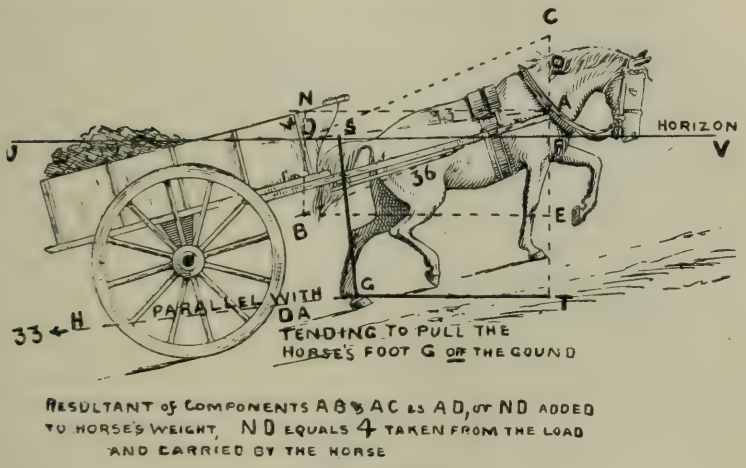


Fig. 331.

down the shafts. Since *AB* and *AC* are the forces necessary to produce motion, by completing the parallelogram *ACDB* we find that *AD* represents the resultant of the forces *AC* and *AB*. Thus we determine one arm of the lever, *GS*, acting against *GT*, the other arm. *GS* is a line drawn at right angles from the resolved angle of force *AD*.

Let us make it clear that if the load had been balanced on the axle, then, regardless of the angle of trace or hame-chain, the virtual angle of draught exerted would be through *AB* to the centre of the wheel. Then a line at right angles with *AB* to *G* would have been the short arm of the lever, which would have enabled the horse to have pulled a much greater load than possible by the longer arm, *GS*. But, due to the load being behind the axle, the forward weight

of the animal is reduced by the lift of the shafts at the point A, and the result is the same as if the traces had been put up at the point D, and the load, with a 33-lb. pull through such a trace, would be exactly balanced and no lift at that moment would be exerted at the belly-band. Neither would there be any depression at the backband, although the trace would be so much above the centre of the wheel. In other words, the tendency of the load to rotate backward would, by such a trace (AD, with a 33-lb. pull), be counteracted. There would be equilibrium, and the horse, so far as his power to pull is concerned, would be acting under the same conditions as though he had the lift at the belly-band and his trace at the centre of the wheel.

A resultant pull of 33 lbs. through AD is equal to the thrust on the horse's hind foot in the direction HG, tending, as will be observed, to draw the animal's foot off from, instead of into, the ground, thus causing him to slip sooner than if the resultant had been either parallel with the road, or, especially, if it had been digging into the ground. This resultant ought now to be treated as a component, together with the horse's natural and added weight on hind feet due to the pull and the gradient.*

Let UV represent the horizon passing through the point D. If DA represents 33 lbs., then FA will represent 4 lbs., so that 4 lbs. must be added to the horse's natural weight by the pull AD. Or, if the pull through the trace AB is 36 lbs., then, drawing BE parallel with the horizon UV, EA (14 lbs.) will represent the depression due to a 36-lb. pull through AB. But, when the lift due to the shafts, 10 lbs., is deducted from the depression of 14 lbs., there remains as before an increased weight of 4 lbs. on the horse.

But when the same horse is pulling with the same force upon a level as in Fig. 332, we find that results are very different from those when pulling upon an incline. Let PA be the direction from the hame to the centre of the wheel and represent a 36-lb. pull. The load having been moved farther to the rear, the lift at the belly-band is still 10 lbs. at P. The load is moved backward to shift the centre of gravity. The resultant of the two components PA and PB is PC, and PC now equals about 35.9 lbs., whereas the resultant AD in Fig. 6 is only 33 lbs., or 2.9 lbs. less than on the level. It will now be found that 36 lbs. pull through PA will increase the horse's weight 4.5 pounds, represented by PO, which

* Complete diagrams on application to the Author.

is determined by drawing AO from A parallel with the horizon, cutting the line of gravity PE. But, as the disposition of the load is such that 10 lbs. are taken from the horse, it is obvious that, if only 4.5 lbs. are put back by the said pull of 36 lbs., the horse has still 5.5 lbs. less than his natural weight in Fig. 333, while in Fig. 331 he has 4 lbs. more than his natural weight.

It is essential that we should know why this difference is brought about; otherwise, we should not know why horses have greater difficulty in climbing hills with loads than travelling on the level. Neither could we have an intelligent idea how to mitigate the evil, or how to assist the animal in the duties he is called upon to per-

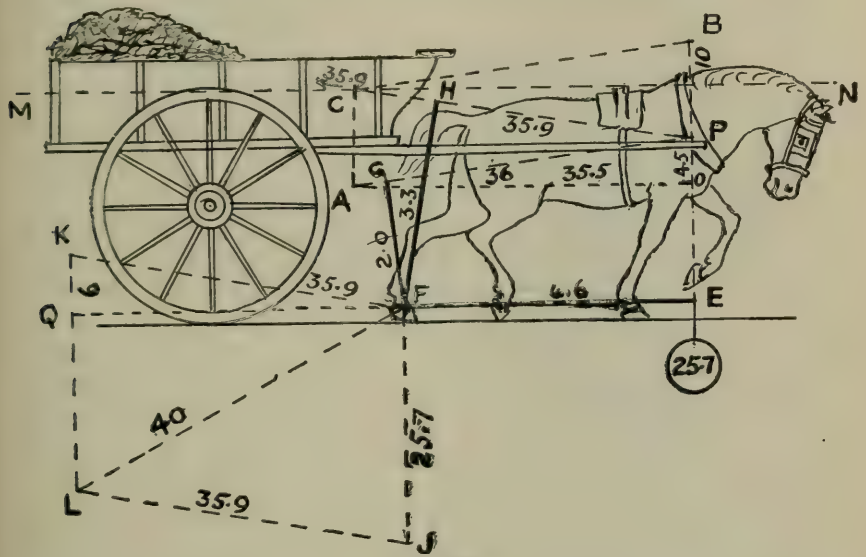


FIG. 332.

form. In all cases it is absolutely necessary that we should know, not only the pull through the trace, which the horse is exerting, but we must know the exact force exerted by the animal, either through the backband or the belly-band, according to the disposition of the load. The one or the other of these forces is of just as much importance as the pull through the trace. And yet, strange to say, they have been practically ignored in the past, with lamentable results.

Inasmuch as these forces are continually changing, due to the inequalities of the road over which the horse is travelling and to the strides of the horse, they must not be considered as constant, although

no perceptible change is taking place. They exist only momentarily, varying in proportion to the irregularities of the roadway or the unsteadiness of the gait of the horse. These irregularities intensify and diminish the lift and depression very much for and against the horse; to such a degree even, that, should he happen to get his propelling foot upon a hard or slippery surface at the moment when the forces referred to are against him, he slips and receives a strain or is thrown.

If the load be shifted to the front end of the cart, as indicated in Fig. 333, the resultant of the forces PJ and PK lies in the direc-

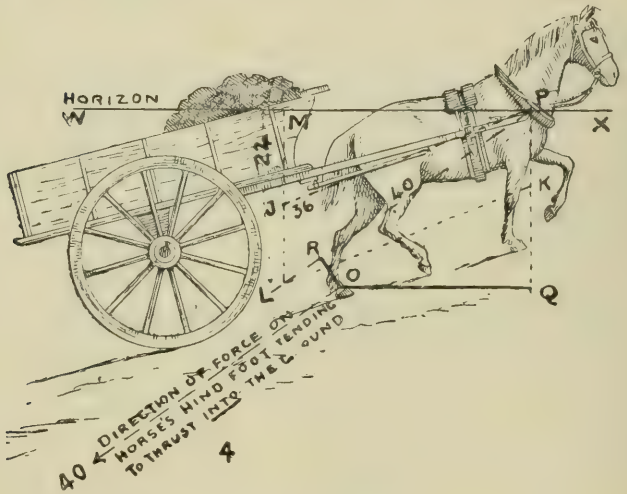


Fig. 333.

tion of PL, and the added weight on the horse is 22 lbs. instead of 4 lbs. as in Fig. 331, tending to thrust his hind foot into the ground at O, and he is able to pull 40 lbs. as against 33 lbs. under the conditions indicated in Fig. 331.

A word now as to the difference between the resultants when pulling up a gradient and on a level plain, the latter being soft or stony ground requiring exactly the same pull through the trace as when climbing the gradient. It will be observed in Fig. 331 that the point of application of force A (the hame) is above the horizontal line UV, drawn through the point D, this being the point at which the traces might be fixed with an advantage equal to having them attached to the axle when the given lift is exerted at A, with a lift at the belly-band as set forth; whereas P, the point

of application of force in Fig. 332, is now much below the horizontal line MN, drawn through the point C on the resultant, or virtual line of draught. Therefore, if we now compare the triangles of forces, ABE (Fig. 331) and PAO (Fig. 332), we shall find a great difference. AB and PA represent the pull through the traces, and, inasmuch as they are not at the same angle with the horizon, although the force in each is precisely the same—viz., 36 lbs.—the result upon the horse is quite different.

If AB in Fig. 331 represents a 36-lb. pull, and AC a 10-lb. lift, then AD (33 lbs.) is the resultant direction of force applied by the animal. Now it will be found that a 36-lb. pull through AB, together with a lift of 10 lbs. through AC or a pull of 33 lbs. through AD, will both be effective in lifting 2.6 lbs. from the horse's fore quarters.

The question has been asked, "Should the horse support the vehicle, or the vehicle the horse?" I will refer to the bicyclist in answer. It is obviously clear to all that the man can travel very much farther and easier when riding his machine than if he were to walk and carry it. In like manner, on similar roads, where resistance to traction is small, it is equally easy for the horse, if at such times the vehicle is made to carry as much of the horse's weight as possible. But while it is clearly right for the bicycle to carry the man on a hard and level road, the condition and the inclination of the road might be such as to make it actually necessary for him to get off and carry a part or the whole of his machine. The same principle will apply to the horse and his load.

In further elucidation of this question, I will repeat the results of some experiments. Having hired an out-porter with his baggage-cart, I borrowed three sacks of iron bolts, weighing 112 lbs. each. The cart weighed 70 lbs. and the man 168 lbs. In the first experiment the load was disposed as in Fig. 334. Attaching a dynamometer to the shafts at point P, I found it required 110 lbs. pressure, bearing vertically downward, to prevent the shafts from being thrown up into the air. To counteract this force, a weight of 110 lbs. must, of course, have been taken from the man. Consequently, in his effort to thrust the 3 cwt. up the hill, a gradient of 1 in 12 on an ordinary roadway, he failed completely to move it away from the scotches placed to prevent the vehicle from running backward.

Mr. James Dredge, Honorary Member of your Society and one of the Honorary Presidents of this Engineering Congress, when he

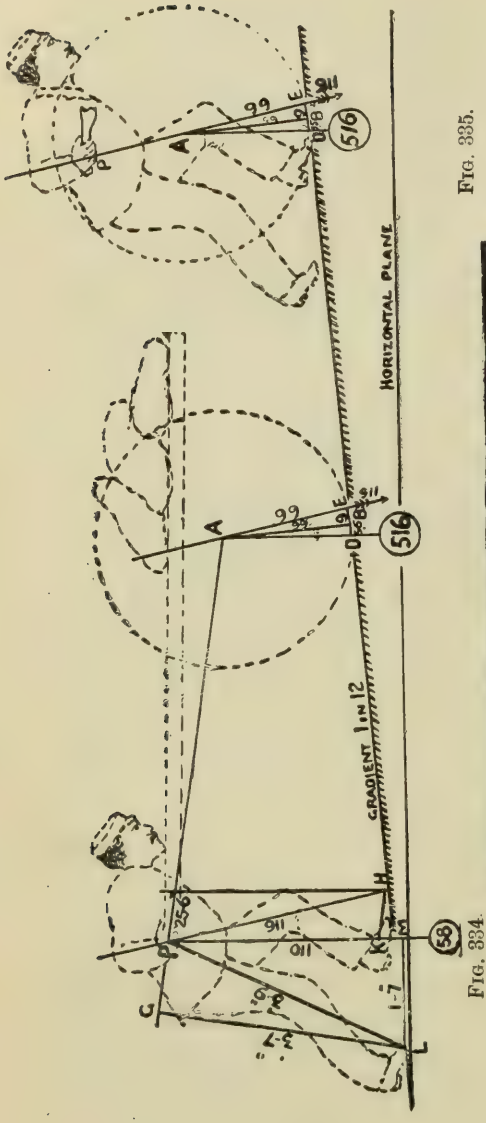


FIG. 334.

FIG. 335.

Fig. 334 is no stretch of imagination, but taken from life.

saw my four original diagrams, kindly and very wisely suggested that another, showing the load still farther from the man, would entirely suspend him in the air, and thus make it unmistakably clear that the man would have no possible control over the load whatever. Such a diagram is produced in Fig. 336.

In my second experiment I moved the sacks of bolts nearer to the man, and added to their weight seven boys—all there were about—as illustrated in Fig. 337. Again I asked the man if he could move the increased load on the same hill and from the same spot. He made the effort, and, to his own surprise as well as that of others, he succeeded, walking up the hill with the 7-cwt. load, although in the first experiment he could not manage even the 3 cwt.

The results of these experiments are somewhat startling to many people. This ought not to be the case, since the results, like all other phenomena, are governed by law, and not by chance. When we understand the law, there is nothing whatever to marvel at.

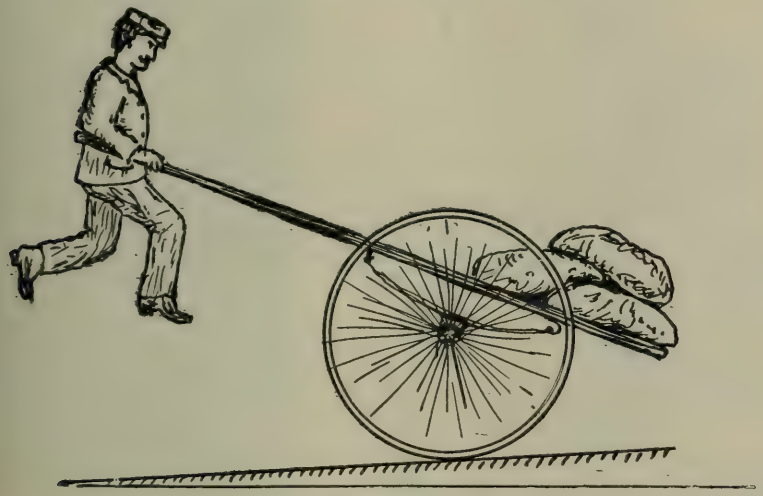


Fig. 336.

Let us examine the conditions, and see why the man could not move the 3 cwt. in the first experiment, but could move more than double the weight on the same gradient in the second experiment. In the first case the load had the greater mechanical advantage, and the man was compelled to submit to the greater power. I have said that 110 lbs. of the man's weight were required to prevent the shafts from being tilted. Thus of his natural weight only 58 lbs. remained on his feet. This weight, even if the man's feet were spiked to prevent slipping, acting upon the lever LM (Fig. 334), which was 1 foot 7 inches long, against LG, 3 feet 7 inches long, could only effect a thrust through PA equal to 25.6 lbs. This force was totally inadequate to compete with the load of 336 plus

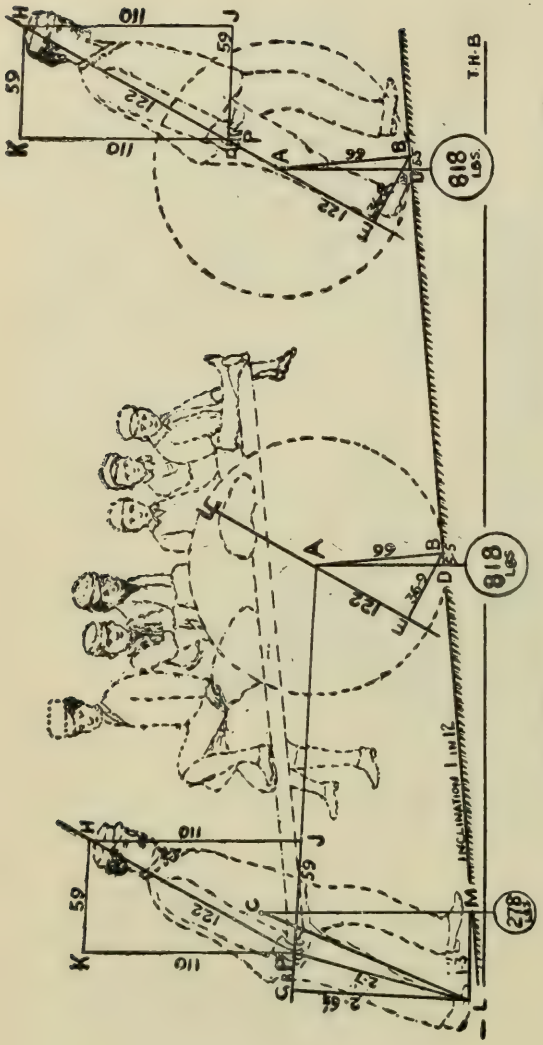


Fig. 338.

Fig. 337.

70 lbs. (the latter the weight of the cart) plus 110 lbs. (the man's weight), a total load of 516 lbs. on a gradient of 1 in 12. Even if the man had been thrusting in a line parallel with the plane, thus getting the advantage of the full leverage of the wheel, he would have required a force of 43 lbs. through that line. However, he was not thrusting parallel with the plane, but obliquely downward;

therefore even still more of his weight than the 110 lbs. was placed upon the wheel by such a declining thrust. The resultant force due to the components PK (110 lbs.) and PJ (25.6 lbs.) was equal to one force of 116 lbs. in the direction of PH. So that, if the gross load of the bolts and cart (336 lbs. plus 70 lbs.), 406 lbs., were balanced on the wheels, and the man were to thrust directly through the centre of the wheels in a direction AE, parallel with PH, the effect, both upon the wheel and upon the man's foot, would be *precisely equal*.

Again, if a pair of wheels weighing 406 lbs., as in Fig. 335, were resting upon the incline, and the man were so thoughtless as to believe that he could either prevent the wheels from running backward, or that he could thrust them forward by advancing and practically lying down upon them, he would find himself very much mistaken. And yet there would not be the slightest difference in the result as between the efforts indicated in Figs. 334 and 335.

Let us now see what takes place in the second experiment, illustrated in Fig. 337. Although the load is more than double what it was in the first experiment, the man, instead of being partly supported by the vehicle, is supporting 110 lbs. of the load, which consists of 336 lbs. (the bolts) plus 70 lbs. (the cart) plus 412 lbs. (the boys), equal to 818 lbs. minus 110 lbs. supported by the man. The difference, 708 lbs., only requires a force through PA equal to 59 lbs., obtained by the lever LM acting against LG, the former being 1 foot 3 inches in length, and the latter 2 feet 6½ inches in length, this force being represented by PJ, while PK represents the vertical lift of 110 lbs. by the man in the act of supporting the shafts.

By completing the parallelogram $PKHJ$, we find that the diagonal PH gives us the magnitude and direction of the resultant force due to the two components PJ and PK, which is 122 lbs. in a line with the man's arms (which would naturally be the case with such a force).

Again, if we draw EF parallel with PH and through the centre of the wheel, and draw a line BE from the periphery of the wheel where it touches the ground, at right angles with the force EF, then EB will give us one arm of a lever constituted by the wheel, and a horizontal line drawn from B to the line of gravitation will give us the other arm of the lever, BD.

While EB equals 36.4 inches in length, BD equals 5.5 inches. So that, if the total load of 818 lbs. were resting upon the wheel,

and the man were to pull directly from *A* to *F*, he would then move the load *just* as easily and with precisely the same effect upon his feet and arms as when exerting his forces at the end of the shafts, or as if he were pulling at the weighted wheels from *A* to *P*, and the parallelogram *PKHJ* in Fig. 338 is exactly equal to the parallelogram in Fig. 337. The difference between the two diagrams shown in Figs. 335 and 338 is very marked. So is the difference between what the man can do in one way and the other.

Again, it has been claimed that "when a cart is properly loaded a very considerable part of the burden is made to rest upon the horse, and this addition to his weight *tends* to increase his draught power."

If the author of such a statement were compelled to transport a 4-cwt. load over a distance of, say, five or six miles a day, and his master were to insist upon having the load so distributed as that a very "considerable portion," say 1 cwt., rested either upon his hands or upon his shoulders, I appeal to you, would not every one of you be ready to cry "shame" upon such a cruel master? Would he ever again, after his first half-day's work, commit himself to such an amazing statement as that a horse, any more than a man, should be compelled to carry such a burden except when absolutely necessary to assist him when climbing, as in Fig. 337?

I think you will agree with me that such a person, equally with the costermonger, would prefer to recline upon his vehicle rather than be compelled to carry any portion of the vehicle or load when travelling on hard, level roads. If this is clear to you, it is obvious that the vehicle should undoubtedly be caused to render the horse every possible relief by supporting him as much as circumstances will allow, no matter whether it be a heavy cart or sprightly carriage horse.

I should add, before leaving this part of my subject, that the lighter the load the more the vehicle ought to support the horse. When, however, the load increases, the horse ought gradually to lose that support until, with a very excessive load, he ought to support a part of the vehicle himself. This, of course, is a very different thing to the contention that a poor cart-horse, because he travels slowly, should *invariably* support "a very considerable" portion of the load. There is one point, however, that I wish to emphasize. It is this: A load which a horse can draw up any ordinary gradient should never require the horse to support any part of either his vehicle or the load on a hard, level road.

I will now proceed to a discussion of the question as to what should take place when a horse is climbing a gradient. In this case, with a heavy load it is necessary that the horse should support a part of the vehicle. We all know that horses cannot haul as heavy loads up a hill as they can on a level plain, but there are many erroneous notions as to the cause. For example, one of the cleverest practical and theoretical men on this subject has made this statement: "It has been properly observed that horses lose part of their power in drawing up hill because a portion of their weight is transferred from their fore to their hind quarters." And again, he says: "From what has already been said on this subject, it follows that placing the point of traction below the horizontal line is advantageous to the horse in drawing up hill,

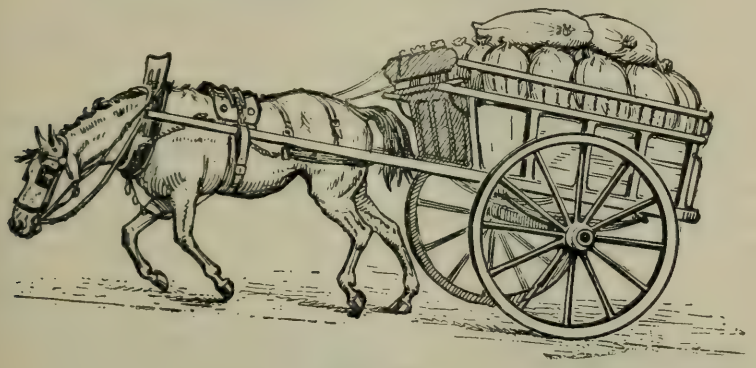


Fig. 339.

because it adds to his weight at the time when he loses force by having the centre of gravity of his body thrown backward by his inclined position on a hill."

It is obvious that the speaker did not understand this part of his subject, for he is entirely wrong. I make the statement at the risk of being considered dogmatic, but I know the facts will sustain me, as I could easily prove to you did time permit. Before proceeding further, I would briefly call your attention to what is known as the limit of the "angle of repose." If I place a body upon an inclined plane and it remains at rest, it is understood to be within the angle of repose; but, if the incline should be increased to such an angle that the body will not rest upon the plane, but will slip down, it is then said to be outside the angle of repose. If this part of the subject had been properly understood in its

bearing upon the question at issue, then the gentleman in question would not thus have committed himself.

Some experiments made by Captain Shaw of the Metropolitan Fire Brigade, London, might easily be made to prove the fallacy

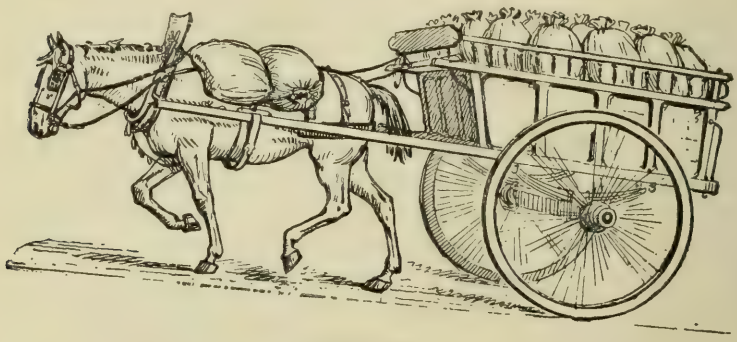


Fig. 340.

of the position just attacked. I will only relate the nature of those experiments. It was contended by certain parties that a horse could haul a ton load up a given hill, and Captain Shaw was made referee. The load was made up of twenty sacks of earth, each weighing 1 cwt., as in Fig. 339. The horse tried to

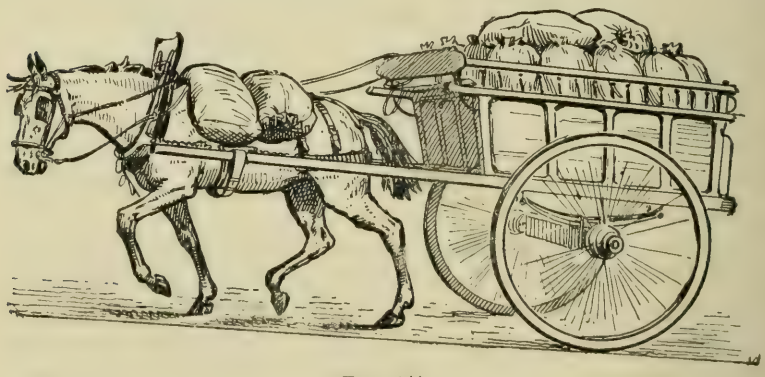


Fig. 341.

haul this load in a two-wheeled cart to which he was attached, but signally failed to get up the hill. Some one suggested that the load was not properly distributed, and two sacks were taken from the cart and placed on the horse's back, as in Fig. 340. The horse tried again, and this time succeeded in climbing the hill. But

Captain Shaw gave a verdict against the horse on the ground that he did not draw the total load, but pulled 18 cwt. and carried 2 cwt. For some reason the verdict did not satisfy even the judge, and he determined to repeat the experiments, but instead of 20 sacks he would use 22. On the following day the horse was required to make the effort to haul the 20 sacks as in the first experiment, but again he failed. Then the two extra sacks, as in Fig. 341, were placed on the horse's back. The result was, as the captain afterward told me, the horse climbed the hill with as much ease, apparently, as he did on the previous day with 18 sacks in the cart and 2 on his back.

The additional weight on the horse's back, together with the pull through the hame-chains, virtually gave the horse a better angle of draught. Captain Shaw was wrong when he said the horse did not pull the load in the second experiment. If he pulled it in one case he pulled it in another.

If there is any difference between pulling and thrusting, a horse does not *pull* at any time; he *thrusts*. The collar and traces are no part of the horse any more than the shafts are. The collar is only a suitable contrivance for the horse to put his shoulders against, so that he can thrust without hurting himself. It does not matter whether the horse thrusts at one angle or another—it is a thrust. But the angle of this thrust depends entirely upon circumstances; it may be a bad one or a good one. If the load is heavy and difficult to move, and the horse is compelled to effect a horizontal thrust and thus not be able to increase his grip and mechanical conditions, he fails. But if the conditions are such that some of the weight is actually removed from the load and placed on the horse, it is only equal to allowing his thrust to be an obliquely upward one, whereby the transference is got by the thrust.

I wish next to relate to you some experiments with a cripple by which he was enabled to haul a 7-cwt. load, although he could not previously have walked a yard to save his life, without his crutches or some such aid.

About three years ago I asserted the possibility of enabling a cripple, who could not possibly walk a yard without assistance, not only to walk but to take with him a loaded wagon weighing from 6 to 7 cwt. Such a man came to me, an engine driver, who, in the year 1879, had both legs cut off, one above and the other below the knee. He had cork legs, and could only get about with the aid of crutches or a machine.

I yoked him to the shafts of a specially fitted wagon, one that I use for experimental purposes. When he was yoked I took away his crutches, and he walked away with my wagon, which contained a gross load of 6 to 7 cwt., greatly to the astonishment of those who witnessed the experiment.

But there was nothing marvellous in the result. There was only an application of a well-known mechanical law, one of which the costermonger makes use every day of his life. The costermonger seeks and actually finds rest in the performance of his work, under certain conditions of road, in hauling his cart; it is actually *easier* to take the vehicle with him than to travel without it, at certain times.

A babe that has not the strength either to walk or to stand alone can actually move fairly heavy chairs about the floor, especially if they are mounted on wheels or casters. The babe, like the cripple, finds it necessary only to recline against the chair or the vehicle, and the falling tendency of the one or the other overcomes its resistance, and motion results. The babe or the cripple needs only to obey the motion, keeping a suitable attitude by the aid of the chair or the machine. The result is precisely what every man seeks when he has any hauling to do.

The better to impress the force of this illustration, it might be well to point out the fact that it is with the greatest difficulty a man can stand quite still for two hours, but he can walk about for eight or ten hours. The natural restoration of energy is so regular and so complete that we can lead an active life of fourteen to sixteen hours' daily labor, with six to eight hours' intervening rest. Exhausted energy is regularly restored, and we are always ready for the new day's work.

A man can haul a loaded vehicle, weighing 5 or 6 cwt., many miles over a level road, more easily than he can stand on the street corners with his hands in his pockets. In this case the principle is the same as that which enables a man to climb a gradient with a bicycle more easily than he can alone. So, too, a man can walk farther and more easily with a walking-stick than he can without it. The same thing is true of the nurse-girl with her perambulator and the boy with his go-cart. The same advantages are secured by the use of the hand-rail in ascending and descending stairs.

In these and in innumerable other instances the muscles of the arms are brought into action unconsciously to aid the legs. We cannot stand in the streets without ridding ourselves of any parcel

we may be carrying. When standing we involuntarily lean upon our sticks, a table, wall, or any convenient object. We seek to relieve the muscles of the legs, which have been doing most of the work. If we have been sitting, we stand to relieve other muscles. We sit after walking or standing. In our beds we shift from one side of our bodies to the other, or to our backs. In short, we are always resorting to methods of relief which relaxation of muscles affords.

Although we have been following these practices from the

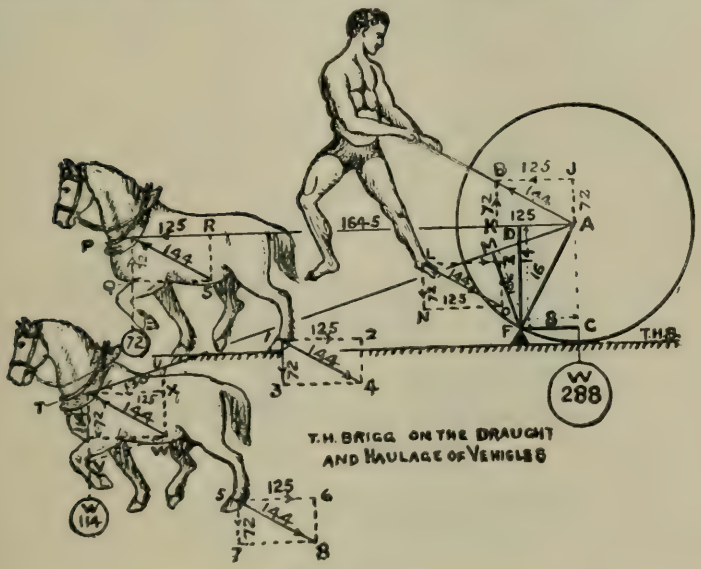


Fig. 342.

very day of our birth, we have kept on yoking our horses, generation after generation, by methods which compel them, in the shafts of a four-wheeled wagon, to rest their entire weight on their feet. They can neither sit nor lie down, nor relieve their leg muscles, except, as is often seen, by resting their heads upon carts or other support in front of them; this affords some relief to the legs. It is not uncommon to see a horse shifting his weight from one leg to another. When tired, the horse shows the same restlessness that a man does. Men are continually moving, resting first on one foot and then on the other, in search of relief. Generally they can sit down, but horses cannot without being smartly beaten for the effort to relieve themselves.

Two of my original and simplest diagrams have provoked much discussion and opposition. This fact alone speaks volumes, and reveals a most remarkable misunderstanding of those mechanical laws which have existed since the world began. In Fig. 342, an obstacle, *F*, is shown in front of the wheels, which are loaded with a gross load of 288 lbs. The best angle at which the wheel can be pulled over the obstacle, so far as the levers of the wheel are concerned, is through the line *AB*, at right angles to the line of resistance, *AF*. If the line of gravity, *AW*, be drawn, and a line at right angles thereto from the apex of the obstacle, we obtain one arm of the acting lever 8 inches long, while *FA* represents the other arm, which is 16 inches

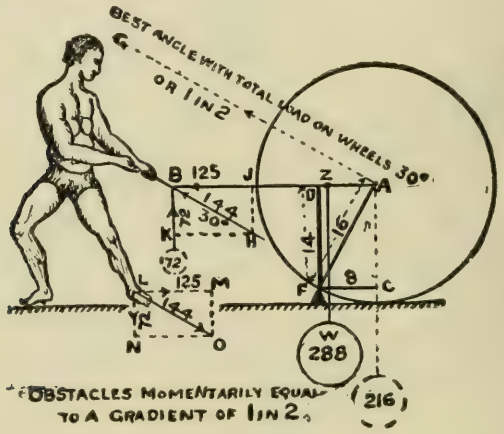


FIG. 343.

long, or twice the length of *FC*. Therefore a force of 144 lbs. through *AB* will support a weight of 288 lbs. at *C*. But if a man or a horse were to pull through the line of *AP*, there would be no longer a purchase of *FA* (16 inches) against *FC* (8 inches), but one of *FD*, which is only 14 inches. Consequently, it would require a force of 164.5 lbs. through *AP* to support the load 288 lbs., or 20.5 lbs. more force through *AP* than through *AB*.

Now, to give the horse or man, pulling through *AP*, the same advantage as that which the man receives by being elevated to pull at the best angle, what I do is to draw a line *PS* parallel with *AB*, and set off on that line 144 equal parts, cutting the

line at *S*. Complete the parallelogram *PQSR*, and determine the proportion of *PQ* to *PS*. If *PS* equals 144 lbs., then *PQ* will equal 72 lbs. Therefore, if the load (288 lbs.) be slid along the line *AB* (Fig. 343) so far as to produce a vertical pressure of 72 lbs. at *B* in Fig. 343, or at *P* in Fig. 342, then it will be found that *PR*, Fig. 342, equals 125 lbs. Hence, if the man in Fig. 343 should exert 125 lbs. in the direction *AB*, together with a 72 lbs. vertical force, the resultant of two such forces would be exactly equal to the oblique force *AB*, Fig. 342, both

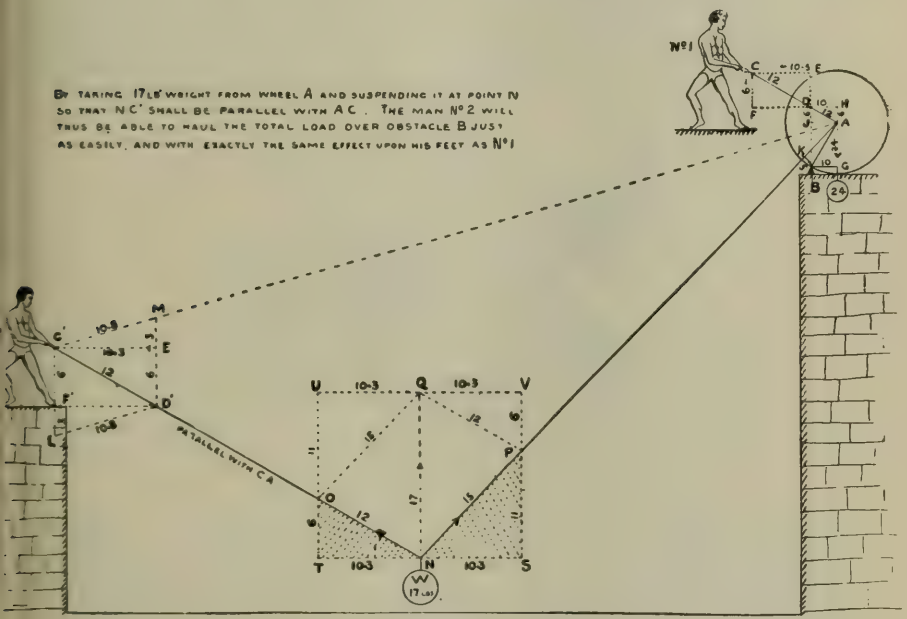

BY TAKING 17LB WEIGHT FROM WHEEL A AND SUSPENDING IT AT POINT N SO THAT NC' SHALL BE PARALLEL WITH AC. THE MAN N°2 WILL THUS BE ABLE TO HAUL THE TOTAL LOAD OVER OBSTACLE B JUST AS EASILY, AND WITH EXACTLY THE SAME EFFECT UPON HIS FEET AS N°1
N°1
PARALLEL WITH CA
T
N
S
W
17 LBS

Fig. 344.

upon the hands and feet, and the parallelograms *BJKA*, *PRQS*, *LMNO*, *BJHK*, 1234, and 5678 in both figures are all equal. But in the case of the second or lower horse (Fig. 342), by reason of his pulling through a downwardly inclined trace, it would be necessary to transfer 114 lbs. of the 288 lbs. from the centre of the wheel to the shoulder of the horse. Thus the two horses are doing precisely the same work, although the pull through the trace and the transferred weight are very different.

In Fig. 344 we have an illustration of an interesting principle, concerning the action of the effort in overcoming an obstacle in

the path of a wheel. Its load consists of wire coiled around its axle, and it requires a force of 12 lbs. through *AC* at right angles with *BA* to raise it over the obstacle *B*. By such a pull the man No. 1 would increase his natural weight 6 lbs. (*CF*), and would exert a horizontal force of 10.3 lbs. (*CE*). For some reason or other it may be necessary that the man should be at a much lower elevation than the wheel, and, say, 1 or even 20 miles away from it. Let this be as it may. If you uncoil the wire, which constitutes the load, so that the man can reach one end of it (you may uncoil as much of the wire as you please, so long as its weight does not increase the weight of the man No. 2 more than 6 lbs.), the man No. 2 can rotate the wheel as easily as if he were in the place of No. 1. The truth of this assertion is ascertained

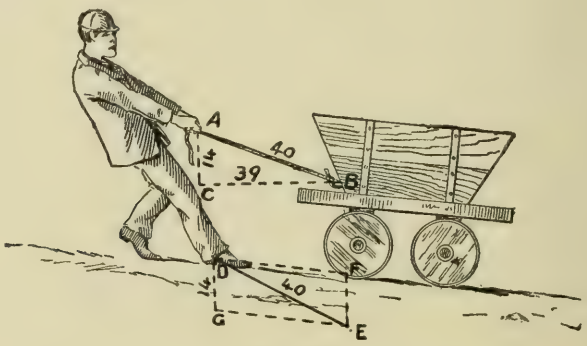


Fig. 345.

by the parallelograms as shown in the figures referred to. If the weight of the uncoiled wire should not be sufficient to increase the weight of man No. 2 to that of No. 1, then an added weight, *W*, might be attached, but *this* added weight *must* be taken *from the load* on the wheels and *not* be an independent load.

Fig. 345 represents a boy endeavoring to haul a truck up a gradient by means of a trace, *AB*. He finds the task impossible, because 40 lbs. is as much as he can exert through the trace without slipping. By exerting 40 lbs. through such an angle with the horizon, he adds only 14 lbs. to his natural weight. The resultant thrust on the ground by his right foot (which will now be doing practically all the work) is in the direction *DE*, which overcomes the resistance of his own and the added weight on the road. But, if the boy gets behind the truck and exerts his forces as an elephant does his (Fig. 328 and Fig. 346), and if the boy were to lift 50 lbs. with his

hands, exerting 39 lbs. through *EF*, the resultant force on his rear foot (assuming it to be doing all the work in this case) would be 64 lbs. in the direction *AD*, which is a very different angle to that of *DE* (Fig. 345). The boy can thus exert to the limit of his muscular capacity without fear of slipping. In fact, if he were to lift, say, 98 lbs. through *GE* and still exert only a 39-lb. thrust through *FE*, the resultant through his legs would be 110 lbs. in the direction *EC*.

I was once told by a professor that the draught power of a horse depended more upon the development of his muscles than upon his bodily weight, and that a light thoroughbred horse, with well-developed muscles, could haul a greater load than a much heavier horse with muscles not so well developed. This statement

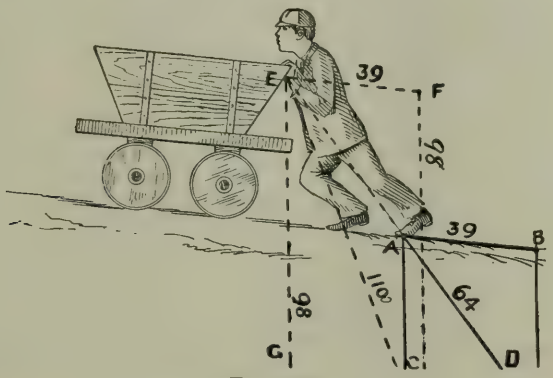


FIG. 346.

I contradicted, asserting that, apart from the extra momentum which the light horse could throw into the traces, the heavier horse could always effect the strongest pull, provided all conditions, excepting those of muscle and weight, were equal. The build and the disposition of a horse will often deceive us if we are not on our guard. Even one nail in the shoe of the lighter and weaker horse may be the means of misleading us.

Very soon after my controversy with the professor I approached Mr. Sandow, the strong man, who had just created a great sensation in London by proving himself stronger than Samson—"the strongest man on earth." He kindly consented to allow me to try any experiments I chose with him to elucidate my views upon the use and importance of muscular development. Such development cannot enable a horse or a man to make a heavier *steady* pull, but

it will enable him to maintain that pull through a much greater space of time, and effect a stronger jerk, imparting greater momentum than could be given by the weaker horse or man.

I placed Sandow on a pivoted foot-board, with an adjustable block to prevent his assuming any other position than the one in which I placed him. In the position indicated in Fig. 347, Sandow, with all his muscular development, could not exert a steady pull of more than 2 pounds against my little boy, then 6 years of age. But when I allowed him to assume the position shown in Fig. 348 he could exert a 40-pound pull against myself, but that was the

Fig. 347.

limit. In that position I could overcome all the resistance he could effect. But, when in the position shown in Fig. 349, I could not outdo him. On the contrary, I might have fagged myself to death by pulling, while he would have been little or none the worse for the effort. His muscles were so well developed that they could endure my pull very much longer than my muscles could maintain it.

Were Sandow to lie down flat and exert his forces in a direct line through his body, there is not a horse in Chicago that could outpull him, since he could then exert the full power of his muscles in a direct line with his body, without being hampered by conditions which, in the preceding experiments, prevented the possibility of his bringing into play the forces he possessed.

Not only are our horses compelled to exert themselves under unfavorable mechanical conditions, on the lines set forth in Figs. 347, 348, and 349, when they are required to haul heavy loads, but they suffer even a greater cruelty at our hands at such times as when the vehicle requires little or no pulling. This I will endeavor to make clear to you by reference to the structure and movement of the locomotive engine, which are familiar to the members of this congress.

Let us, for example, mount a locomotive upon incomplete wheels —spoke-wheels, if they may so be called—wheels without a periphery, and suppose the extremities of the spokes to be 2 feet apart

FIG. 348.

and the spokes themselves 4 feet long. If the total weight of the engine (50 tons) should be resting upon two of these spokes, it would require a horizontal force of more than $12\frac{1}{2}$ *tons* at the centre of the wheel to produce motion in that engine on a level plane, with no tender attached. Yet, if the same load were resting upon a perfectly round wheel, it would move on the application of a force of about 10 cwt., or considerably less than that amount.

Therefore, when we realize the *fact*—for it is a *fact*, whether you believe it or not—that our horses are compelled not only to deal *continuously* with their own weight upon their feet, but also with some of the weight of the vehicle, thus they are caused, absolutely unnecessarily, to waste their strength, life, and energy,

just as would be the case with an engine if compelled to work on a polygonal wheel, with sides measuring from one to two feet in length. It becomes obviously clear to all of you that it is no more possible for a horse to carry his centre of gravity parallel with the plane upon which he is running, when he must rotate first upon one leg and then upon another, than it would be possible to get the same steady run of a locomotive engine upon a polygonal wheel as is secured by the present round one.

From this it is plain that the horse is *compelled*, absolutely unnecessarily, to exert himself under conditions such as no engi-

FIG. 349.

neer in the world would for a moment think of applying to his steam-horse, under which to waste its energies and knock itself to pieces, in, practically, no time. I appeal to you, is there any wonder at our living horses suffering so much by reason of their legs failing them when so brutally knocked about, not only by such unscientific methods of attachment, but by reason of the rough and stony roads over which they travel? I say, gentlemen, there is NO WONDER, unless, indeed it be, that they bear such treatment so long and so patiently. Few people can realize that a horse exerts from TEN to ONE HUNDRED times more force, and expends that much more energy, in transporting himself from place to place than he exerts in hauling a two-ton load on fairly good roads. This is, to my mind, an ABSOLUTE FACT and beyond the power of man to disprove.

We need no further or more forcible example of the vast differ-

ence between the two methods of effecting transportation than is contained in a mere reference to what we ourselves can do. Of course, there is no practical difference between the conditions under which a man or a horse transports himself when in the act of walking; both require a great amount of force, as in the case of the engine on polygonal wheels. If a man starts out on a long walk he does very well if he covers 50 miles in a day, but the same man is not only able to transport himself but to take a machine with him and travel more than 400 miles in 24 hours. Further proof of my contention is afforded by the use of pneumatic-tired wheels, which tend to keep the centre of gravity more nearly parallel with the plane.

Be good enough to put the man on polygonal wheels, when you will find that he will have great difficulty in travelling his 50 miles, the distance, of course, depending upon the length of the sides of the wheels. By adopting such means as those described you put the man back to the unfavorable and extravagant method of transportation which hampers him when walking. I do not wish to be understood as complaining of our construction; on the contrary, we are the most perfect of machines, wonderfully conceived, with brains—if we would only use them—to plan not only our own comfort and pleasure, but the comfort of the noble creatures we are here to consider, interests which I believe to have been sadly too long neglected.

Before leaving the question of the locomotive engine, I should have liked very much to have discussed the question as to what *are* and what *are not* its impelling forces, upon which question I hold very different opinions to those which are said to have been accepted as true by engineers for the past thirty or forty years—before dismissing the locomotive, let me give you one or two simple illustrations, which may tend more forcibly to impress my views upon this important feature of our subject.

In Fig. 350 the sphere weighs 5 cwt. In Fig. 351 the square block has the same weight. Now, it would be quite an absurdity seriously to ask any man which of the two bodies (Figs. 350 and 351) he would prefer to roll along the road. In Fig. 350, B is the point of rotation of the wheel A, and the centre of gravity of the load is directly above it at A, balanced, as it were, and ready to roll either to the right or to the left on the application of the slightest force, provided the wheel is rigid and upon a hard smooth rail.

But the line of resistance in Fig. 351 is *CD* and must rotate about *D*, and *C*, being the centre of gravity, must be literally raised until its altitude is increased from *CE* in Fig. 351 to *GF* in Fig. 352 before the load will roll as easily as in Fig. 350. But, to produce motion at all from the position indicated in Fig. 351, there must be exerted a horizontal force through the centre of gravity *C* equal to 5 cwt. The body would, therefore, remain in its present position forever if its motion depended upon the unaided strength of a man to roll it by a force exerted through its centre of gravity.

The result of my investigations is that, having ascertained the fundamental and economic principles involved in the haulage of vehicles and the transportation of living or inanimate matter, I have devised a special contrivance applicable to all kinds of four-wheeled vehicles or sleighs, which will, at all times, automatically

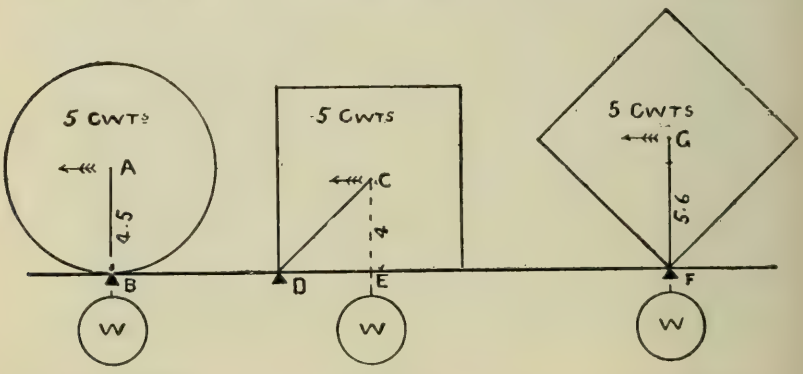


Fig. 350. Fig. 351. Fig. 352.

afford the horse all possible assistance. It does not matter whether he be travelling on smooth, level roads, up hill or down, with a heavy or a light load, he cannot fail to receive a direct advantage from the very moment he is attached to the moment he is detached. The relief is afforded while he is walking, running, or even standing.

The percussion on his feet is reduced at every stride during the day. His muscles are less strained, and his energy is economized as you would economize the energy of a locomotive. He receives that relief on a level road and while going down hill, and in part while going up hill, that a lady would receive by taking the arms of two gentlemen, one on either side of her. The relief is better felt than expressed. The costermonger and others seek for and

obtain it, though they know not what it is. The simple contrivance which I have hit upon, and which gives to the horse all the

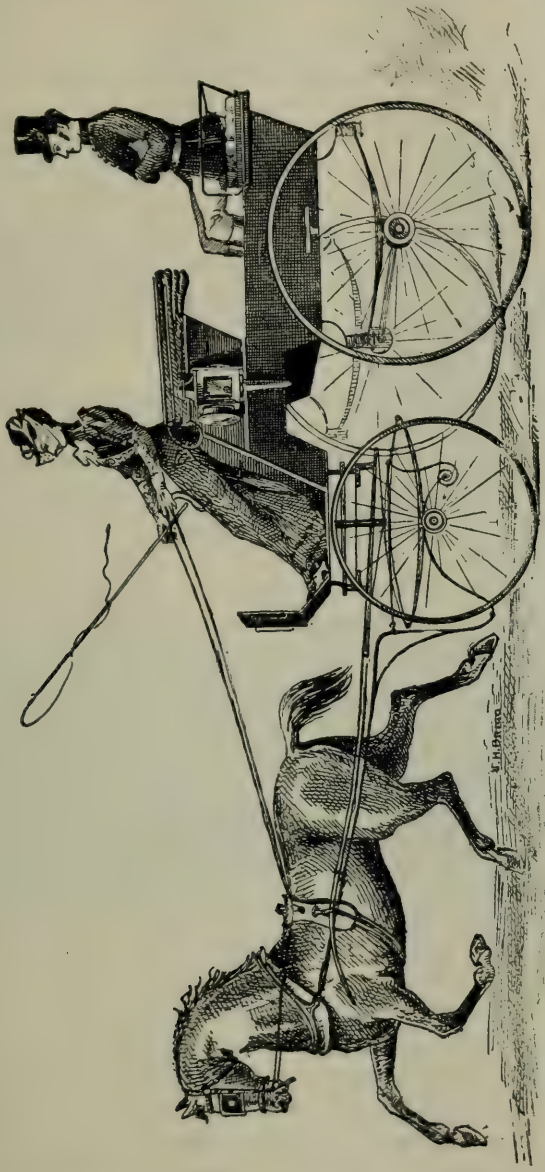


FIG. 353.

The attachment is applicable to the heaviest or the lightest of 4-wheeled vehicles or sleighs.

advantages which men so persistently demand for themselves, has been on exhibition at the World's Fair at Chicago, 1893.

INTERESTING EXPERIMENTS WITH AN AMERICAN-MADE BUGGY BELONGING TO THE RIGHT HON. THE EARL OF LONSDALE, WHO HAS DONE MUCH TO FACILITATE MY INVESTIGATIONS.

The buggy is claimed to be a vehicle of 5 lbs. draught on a level road. I prove conclusively it is nearer 15 lbs.

In America, as in England and other countries, there seem to be very incorrect ideas as to the proper method of testing the draught of a carriage. In testing the draught of the buggy in question, I first weighed the shafts at the point where they are held by the backband to ascertain the force which the horse must exert before he begins to pull. I found the weight to be no less than 9 lbs.; therefore, the animal must exert 9 lbs. vertical force to support the shafts alone.

To ascertain beyond a doubt the direction and magnitude of the force required to travel on any given road, tie a small steel spindle across the shafts at *A* (Fig. 354), passing easily through a strip of wood, or other material. Attach one end of this to a dynamometer, *K*, the latter being supported by a stay, *LM*, supported at the rear of a moving vehicle.

By this simple contrivance we transmit all the forces to the buggy which are necessary not only to carry the shafts, but to draw the vehicle along at any required speed, taking care to keep the shafts at about their normal working height. Not only will the strip of wood then indicate *exactly* the angle of traction, but the dynamometer will indicate exactly the amount of force exerted through that angle. (It will be observed that this angle will be continually changing.)

Instantaneous photographs were taken during the progress of the following experiments. The angle of traction is indicated in each instance by *KO*, on a slight up-gradient. Now, apart from the force registered on the dynamometer, knowing the shafts to weigh 9 lbs. at *A*, set down nine equal parts vertically from *A*, giving us *AD*. Draw *AC* in a line from *A* to the centre of the point of rotation of the shafts, and a line parallel therewith from *D*, cutting a line continued through *KO* to *B*. From the point where *DB* cuts the extended line *KO*, draw *BC* parallel with *DA*, thus completing the parallelogram *ACDB*. Then, if *AD* equals one component force of 9 lbs., *AC* will represent another of 8.1 lbs., the resultant of which will be found in the direction and magnitude of the diagonal *AB*. This shows that the exact force exerted

by the horse is 13.6 pounds, and gives the angle through which such force is exerted to keep the buggy in motion at that particular moment.

Thus we prove that the angle of draught, instead of being through and in a line with the traces, as most people think, is actu-

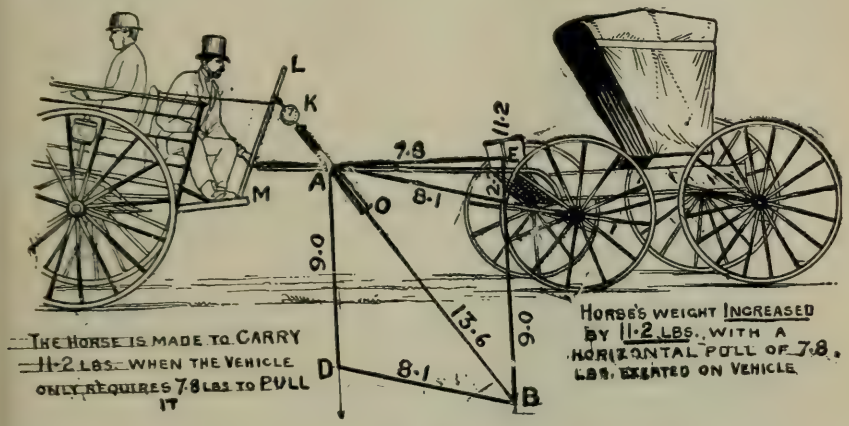


FIG. 354.

From which Fig. 354 is produced.

ally in the direction of the oblique line *AB*, and that the draught is 13.6 lbs. instead of 5 lbs. as claimed.

This diagram further proves that, with such an oblique force through *AB*, there *must be* a vertical force in the direction of the line *BE* of 11.2 lbs., transferred from the vehicle to the horse's feet. Therefore, it is clear that the horse is compelled to carry 11.2 lbs. in addition to his own weight. But the costermonger would have carried less than his own weight (very sensibly, too,

when resistance was so small). This 11.2 lbs. means that there is about 22 lbs. greater percussion on the animal's feet when travelling only about 4 miles an hour, even on level ground, but considerably more when travelling rapidly. (I regret that I am unable to treat of this part of the subject in this paper.)

Without delaying to explain the action of all the forces indicated

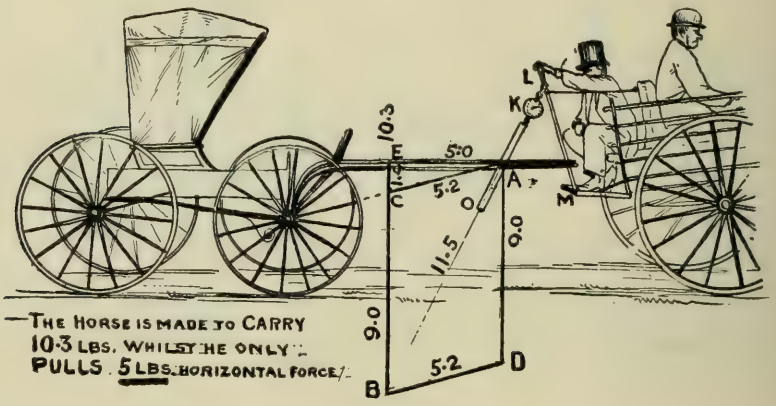


FIG. 355.

From which diagram Fig. 355 is taken.

in Fig. 355, in which the vehicle is shown to be travelling down a slight grade, we find the obliquity of KO is not so great as when the vehicle was moving in the opposite direction over the same ground.

We now find that AC is equal to 5.2 lbs., AD, the weight of the shafts, remaining the same, the resultant AB in Fig. 355 is equal to 11.5 lbs. against 13.6 lbs. in the preceding experiment,

and that the added weight on the horse, even when he is travelling down hill, is actually increased by the amount *BE*, or 10.3 lbs.

Passing hastily to Fig. 356, with the same vehicle drawn by men at a slower rate of speed, we again find that the obliquity of *KO* is not so great as in Fig. 354 (due, of course, to the slower pace). Here we find *AC* equal to 7.6 lbs., *AD* remaining the same. *AB*, 13.3 lbs., is now the resultant angle, and the magnitude of the force exerted to draw the vehicle—not merely 5 lbs., as shown by easy reasoning.

In Fig. 357 we have quite different results. By means of a special contrivance a lift is effected at the belly-band, or at the point *A*, equal to 24.1 lbs., so that when the weight of the shafts is

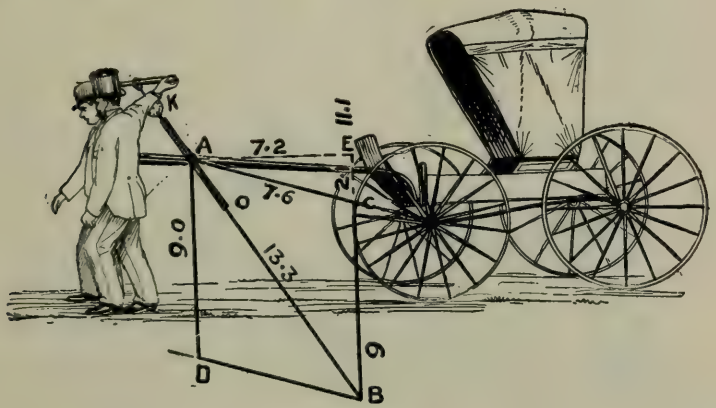


Fig. 356.

deducted from that amount we still have a lift of 15.1 lbs. at the belly-band. To resist this lift, and at the same time produce a forward movement of the vehicle, it is now found that the men must *pull down* at the dynamometer, and that *KO* is the resultant direction of the components *AD* (15.1 lbs.) and *AC* (7.1 lbs.). *AB* is the magnitude of this force, which is equal to 14 lbs. exerted in the direction from *B* to *A*, thus reducing the weight on the men, or the animal pulling, by 15.1 lbs., instead of increasing it as in the preceding experiments, making a difference of 15.1 plus 11.2 minus *CE*, 2.7 lbs., equal to 23.6 lbs. less weight to be carried on the horse's feet, or a percussion less by 47.2 lbs. at every stride, when the horse is travelling at a speed of four miles an hour. Multiply this by the number of strides he takes in a day divided by four, and you will appreciate the difference in the effect upon

the horse, and will see how work is done unnecessarily, energy wasted, and discomfort increased.

To realize the practical effect of the difference between a light and a heavy blow, let us tap gently with our knuckles upon a hard, fixed stone. We feel, perhaps, that we might go on knocking without suffering. But, striking a harder blow, we soon find that we must cease the operation.

Take another illustration, as indicated in Fig. 358, where the forces are applied by a man hauling a cart weighted, as shown, at the rear of the axle. In this case, as in Fig. 357, the dynamometer must pull downward and forward to prevent the shafts from shoot-

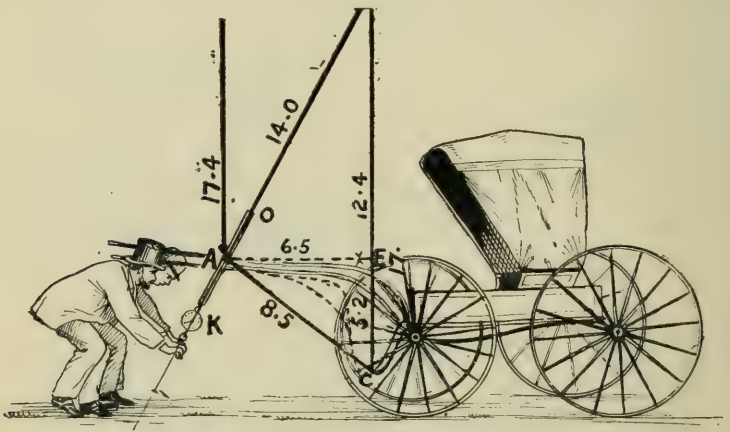


FIG. 357.

(Taken from a Photograph.)

ing upward, and to cause the vehicle to move forward. In this case we have clearly set before us the conditions which men find from experience to be so conducive to their own comfort. It is to these conditions I wish to draw your SPECIAL attention, since I believe they are THE ONLY CONDITIONS upon which ECONOMIC HAULAGE CAN POSSIBLY be effected on fairly good roads, and where heavy gradients are not encountered.

In Fig. 358 the load W (67 lbs.) is so disposed that a force F (42.8 lbs.) is required at P, acting vertically downward, to produce equilibrium in the lever PJH, of which J, the centre of the wheel, is the fulcrum. It is obvious that the wheel is supporting not only the 67 lbs., the weight of the boy, besides that of the cart

body, but is supporting also 42.8 lbs. of the man's weight; but, mind you, only when the cart is at rest.

To ascertain the angle and magnitude of draught required to haul this load, let us refer again to Fig. 358. The dynamometer *K* with the slip of wood, as used in the preceding experiment, is again brought into use to prevent the shafts from tilting upward, and to keep them at about the same angle as when hauled by the man in Fig. 359. We find by the parallelograms *ACBD* and *AEBN* (Fig. 358) what are the component and resultant forces which are required to produce the desired advance. The force *AD* (42.8 lbs.) is determined by the disposition of the load on the lever *PJH*.

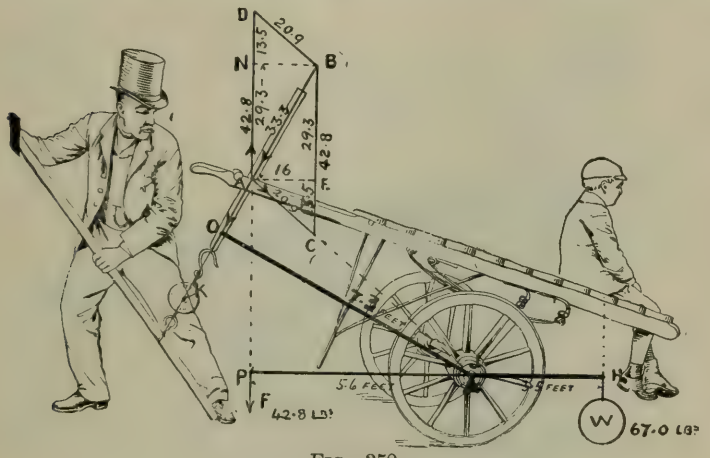


FIG. 358.
(*Taken from a Photograph.*)

Let us then set off 42.8 equal parts on the vertical line *AD*. Draw *AC* to the centre of the wheel and *DB* parallel with that line, cutting *AB* (an extension of the line *KO* running through the dynamometer), and from *B* draw *BC* parallel with *AD*, thus completing the parallelogram of forces exerted by the man.

Although a vertical force of 42.8 lbs. is required at *P* to produce equilibrium, the vehicle still at rest, it may seem remarkable that a single force of 33.3 lbs. exerted through *BA* will not only balance 67 lbs. at *H*, but will propel the vehicle at the same time. The action of the force *AB* (33.3 lbs.) may be considered in two ways.

1. *BA* being the direction and magnitude of that force, if we draw a line from the centre of the wheel *J* to and at right angles with the extended line *BA*, cutting it at *O*, we shall find that *OJ*

represents the leverage which a force, BA, has upon the short arm of the lever JH, and that, as OJ measures 7.3 feet against PJ, 5.6 feet, BA will slightly more than balance 67 lbs. at H, and that, by reason of the obliquity of BA, a horizontal force of 16 lbs. in the direction from E to A is imparted to the vehicle, which now causes it to move on a slight up-gradient.

2. From the fact that a force of 42.8 lbs., acting vertically upward, is exerted at A by the weight W at H, there does not follow the conclusion that the total weight is taken from the man's feet when the vehicle is at the point of motion, for the simple reason that the vehicle will not run up hill without an external applica-

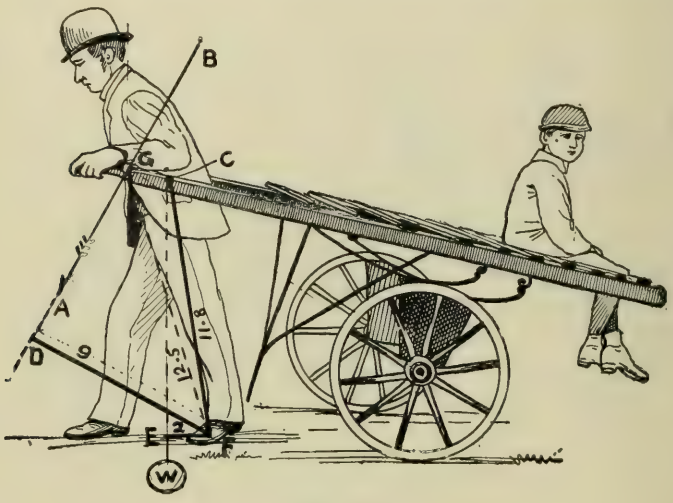


FIG. 359.

tion of force. This force is represented by the component AC, which equals 20 lbs. Well now, to resist a force of 33.3 lbs. through BA in addition to the 42.8 lbs. through AD, it will require another force of 20 lbs. through AC to counteract BA. Therefore a pull or resistance of 20 lbs. by the vehicle from the centre of the wheel in the direction AC will be effective in bringing CE, 13.5 lbs. of the 42.8 lbs., back on the man's feet when the load is at the point of motion. So that the reduced weight on the man's feet, which he feels to be of such great relief to him, is 29.3 lbs.

By this reasoning it is clear that, although the vehicle, while at rest, might take a given number of pounds from the horse's feet, it depends entirely upon whether the virtual angle of pull is above

or below the horse's hame-hook to determine whether the horse's weight is increased or diminished.

As to the effect of added weight upon the feet of a man or a horse when travelling, it is seen in the evident and appalling AGONY inflicted upon the carriers of the sedan-chairs at the World's Fair grounds. This is the most horrible sight to be seen at the World's Fair.

Refer to Figs. 360 and 361, in which the load is represented as consisting of a small boy. Our costermongers would as soon think of flying as to haul him about the streets, placed in the position shown in the illustration. It is to be noticed, in this case, that the man is

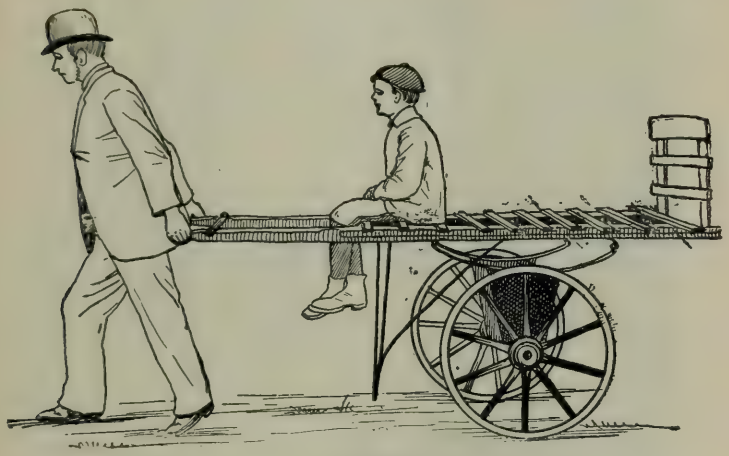


FIG. 360.

not bearing half the boy's weight. Then think of the weight of the sedan-chairs, and a 14-stone man within smiling at the misfortune of those who are being almost tortured to death by the weight of his heavy idle bones. It is an act of extreme cruelty thus to suffer one's self to be carried when there are other and easier means of transportation, even though one suffer in carrying his own weight upon his wellnigh exhausted muscles.

From the standpoint of commercial advantage, which may appeal more forcibly to the world at large, is there not a most urgent demand that we lessen the burdens placed upon the horse? We have seen that the costermonger, who knows no more than his cart about natural law, when hauling his wares, acts in perfect harmony with natural law and unquestionably in accordance with com-

mon sense. When we plot out the forces which this ignorant man brings into action in moving his cart, no matter whether his load be heavy or light, whether he be travelling up hill or down, or upon the level road, the application of the resultant is found to be mathematically correct, notwithstanding the man's absolute ignorance of mathematics. This is not to be wondered at, since man, when a free agent, seeks to obtain all the ease and comfort he can, and when doing his own work is sure to find out the easiest way.

Experience alone has taught the costermonger how to deal with his load and how to relieve himself of unnecessary burdens. It is

Fig. 361.

not a matter of indifference to him where he places his load, or whether he shall push or pull his cart. To him his methods are everything, and he rightly persists in his usage. On the other hand we, who boast of our education and civilization, are acting in defiance of natural law and common sense by so yoking our horses as to compel them to do their work under conditions such as no man would for a moment consider in the execution of his own work.

It can also be shown that the usual application of the effort of a draught animal in holding back and in backing is most unnatural and inefficient. Drawing the lines of effort and resistance as shown in Fig. 362, it appears with the ordinary attach-

ment the horse is working to increase the load on the vehicle and therefore to lighten his own adhesion to the roadway.

In Fig. 363, on the other hand, where the horse is pushing upwards and back the resistance on the wheels is lessened, and his weight, and hence his capacity, is increased. Fig. 364 shows the distribution of forces when the reaction is a mean between the other two.

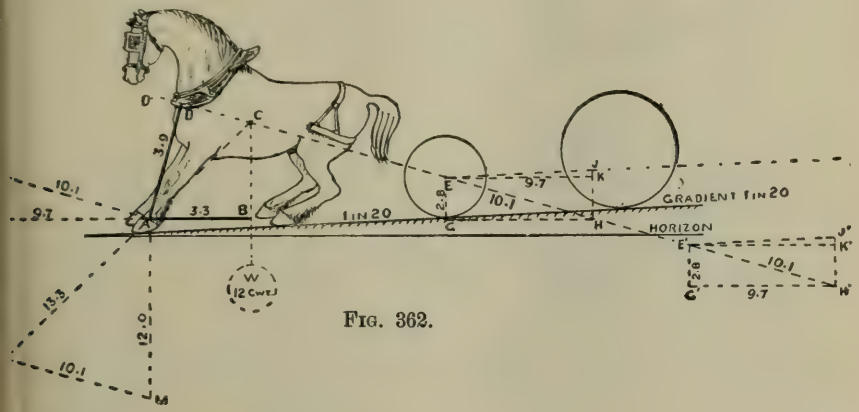


FIG. 362.

The data and conclusions from these diagrams can be thus summarized :

The angle of thrust by the horse's feet upon the ground being within the angle of repose :

The horizontal force exerted on the vehicle—

Fig. 362 = AO, or 9.7 cwts.
Fig. 363 = AV, or 22.8 "
Fig. 364 = AI. or 13.2 "

The following are the loads which each horse can keep in equilibrium, when mounted on wheels on a gradient of 1 in 20 :

Fig. 362, 194 cwts., or 9 tons 7 cwts.
Fig. 363. 456 " or 22 " 8 "
Fig. 364, 264 " or 13 " 2 "

Horse's weight on fore legs :

Fig. 362, 9.2 cwts. Reduced by 2.8 cwts.
Fig. 363, 21.6 " Increased " 9.6 "
Fig. 364, 12.7 " " " 0.7 "

Horse's natural total weight, 12 cwts.

Time fails me in my attempt to lay before you hundreds of interesting diagrams, based upon scientific facts, and bearing upon this important subject; therefore, I have tried merely to impress upon you the fact that the subject is one well worthy all the

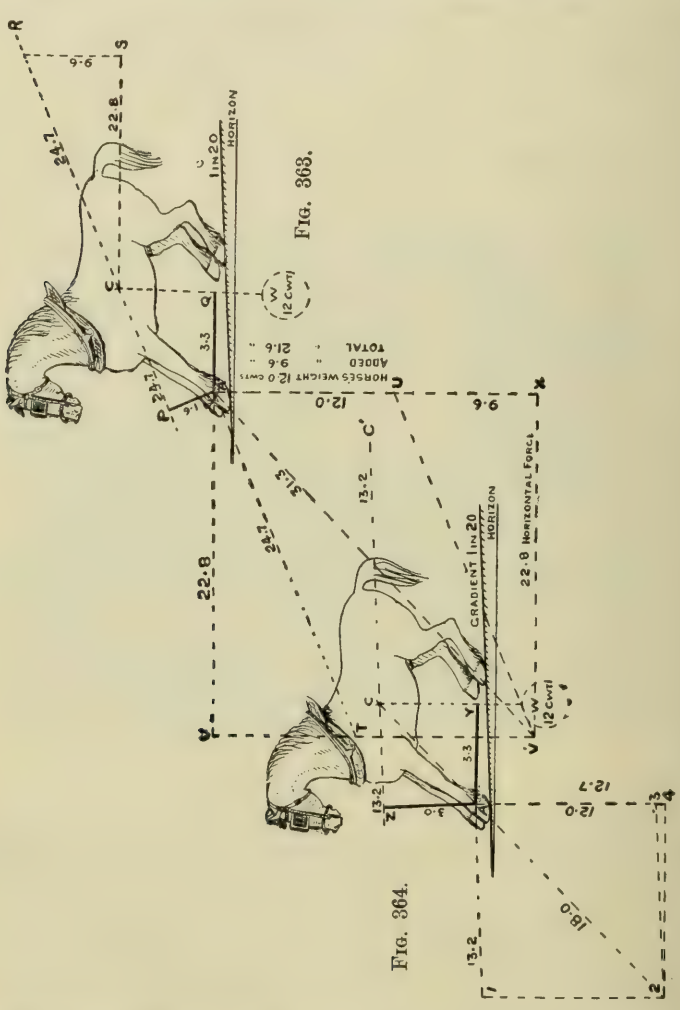


Fig. 363.

Fig. 364.

intelligence that can be brought to bear upon it. Although it may relate to the common draught of a horse, it embodies principles which have *never yet been* practically applied, and principles which NO MAN need be ashamed to understand, whether they be applied to the *steam engine*, *steamboat*, horse, or a million other subjects.

I am profoundly impressed with the importance of the subject, and I trust this congress, representing the profession which, more than all others, helps the world on to better things, will give it the consideration it deserves. It may seem a simple matter to aid the horse in his work, and one of no particular importance, because he is a brute and toils at our bidding. On the contrary, as I have shown you, it is a question in which the humanity of man is involved, one which should no longer be permitted to defy scientific principles, and one upon which commercial prosperity so largely depends.

DISCUSSION.

Professor R. H. Thurston.—I have been very much interested in listening to the presentation of this paper by its author. I think, with him, that it is an important matter, and I have no doubt that we shall find, upon proceeding on the lines of experiments which he has indicated as being best and most desirable, that we have more to do in the development of horse power in this country than we have yet to accomplish in the development of the steam-engine, because the latter has already reached a very high stage of development, while, in the application of horse power, the methods of application to useful purposes are comparatively crude, and subject to very great improvement.

I would simply say that I believe this is a subject which not only is very important as a matter of philanthropy, but commercially of very great value. If you will take the trouble to examine the census returns, and will observe the number of horses doing the work of the country by haulage, you will find that more millions are involved in the proper adaptation of the horse to his work than are involved probably in any other direction than in the application of steam. The adjustment of weights between the horses and the vehicles which they haul is evidently one of, perhaps, the prime, necessity; and although we see rude attempts at such adjustment on all lines, yet they never have been perfected. The old-fashioned chaise was one of the best illustrations of good adjustment; but instead of going forward in this direction we have gone backwards. If we compare the condition of the horse which is driven all day harnessed to a London hansom cab with that of the horse driven all day attached to a four-wheel vehicle, I think we shall find that the horse driven before the hansom cab comes out very much fresher at the end

of the day's work. As an illustration of how far that may be carried, I might state an experience of my own, which occurred years ago, when I was a mere boy. I had occasion to go from Providence, R. I., to Bridgewater, Mass., to order heavy machinery. (In those days we were not prepared to make heavy forgings or very large castings at Providence.) The establishment to which I went was located in the city of Bridgewater, some ten miles distant from Taunton. In going from the railway station at Taunton, across country, to Bridgewater, it was necessary to take a horse and carriage. In making that trip I used generally to drive a little, hollow-backed mare that weighed only about six hundred pounds, hitched to an old-fashioned "chaise." When properly harnessed to the chaise the shafts lifted, instead of bringing weight upon the horse's back; and that little creature—the lightest animal I ever drove—would carry me over that ten miles in fifty-five minutes, and I always brought her in perfectly fresh. Going over the same route at other times, with other horses and other vehicles, I was never able to make the same time or bring the horse in so comparatively fresh. Although that is, perhaps, an amusing illustration of the general principle, I think it does illustrate the principle that we must adapt our horses and our vehicles to the load in such ways as are described in this paper, and I have no question that ways will be found of so making this adaptation as to increase the day's product of work from horse power, by a very large percentage, adjusting weights to give just the right "adhesion."

I am sure the author is perfectly right in saying that it is a matter of enormous importance, both intrinsically, as a matter of humanity, and commercially.

Prof. F. R. Hutton.—I would like to say that the subject of Mr. Brigg's paper has excited in my own mind considerable interest. I think, where the motor is a motor endowed with volition and acting by instinct, either human or brute, we fail to appreciate always the direction and the application of the forces in play.

The subject of the paper is a broad one, and ramifies into many interesting and important side issues, but I apprehend that the following are fundamental contentions, which I believe to be sound in an eminent degree:

(1) The hauling draft animal is a machine. His motor force being vital, requires, therefore, to be refreshed, and will endure

longer where his effort is diminished, than where no such attempt is made to make his work easier. This is a money question affecting the value of the horse as an investment, apart altogether from any considerations of a sentimental character as to man's relations to the animal creation.

(2) The power of a draft animal, like that of a locomotive, is limited not alone by his muscular development. The limitation is set in advance of the muscular limit by the ability of the animal to hold his feet, without slipping, upon the ground where he has put them. In other words, the limit is fixed by his adhesion to the roadway, which, by the laws of mechanics, will be greater as his weight is greater. Hence, for heavy exertion, it is an advantage to increase the weight of the horse, by the way in which he applies himself to move his load.

(3) The element of fatigue and exhaustion in walking is not solely due to the product of the weight into the distance moved, nor is it measured by that product. Fatigue in walking is due to the necessity of lifting the weight of the body at each step through the distance which the center of gravity of that weight descends when the body falls forward in its rotation around the foot which is upon the ground, and acts as a fulcrum. A bicycler moves the same weight as the pedestrian through the same distance in any given level course, and propels his machine in addition, but the former does not have to lift or carry his own weight on a level, and hence can cover much more ground than the pedestrian in a given or less time, with the same fatigue.

(4) Except when the direction of resistance to the effort of a horse passes through the contact of his hind feet with the ground, the elbow-joint press, which is the elementary machine through which his muscles act, is directed to lift the weight of that horse, so that it is the weight of the animal, rotated around his heels as a centre of moments, which measures his muscular hauling power within the limit of slippage on the ground. It is thus the massive weight of ox or elephant, or Norman horse, which enables him to start heavy loads, and not a high development of extensor muscles, such as may appear in a lighter-framed roadster.

(5) Such a disposition of load or such an attachment of the hauling line of connection between the motor horse and the resistant load as will increase the weight carried by the horse on his feet, will tire him the sooner. If the horse can be

relieved of his own weight in part, on levels or descents, his endurance will correspondingly and largely be increased.

(6) Resistance of vehicles on a level is made up of two distinct elements: first, a constant friction for any weight, due to the product of that weight into a coefficient, which latter is made up of the allowance to be made for friction between hubs and axles, and for that friction which is called rolling friction. A second element is the resistance caused by obstacles in the path of the wheels, making it necessary that the weight of the vehicle be lifted through the space commanded by that obstacle. There should be on a level a gain from the descent of the vehicle, but as a rule lost motion in connections causes this gain to dissipate, and the loss only is experienced. The first resistance will obviously be diminished as the weight diminishes upon the axles or the ground, and this object will be attained by attaching the hauling or thrusting connections as low down as possible, so that the effort of haulage shall have an upward component, whereby part of the weight shall be taken off, thus lessening both the frictions. It is obvious, however, that this process will add weight to that carried by the horse, and will fatigue him the sooner if such addition of weight is unnecessary. The second element of resistance will similarly be diminished by inclining upward the hauling effort from wagon to horse, just as a wheelbarrow, or a child's perambulator, is most easily drawn up upon a curbstone or a doorstep by a pulling action in front of the wheels which carry the weight, while upon a level both vehicles are more easily pushed by a thrusting effort from behind; because part of the weight of the operator is transferred to the vehicle, in accordance with the principle outlined in paragraph five.

In view of the foregoing sound principles, based upon accepted theorems of mechanics, illustrated by the experience of generations, and confirmed by the photographs presented by the author from practice, with explanatory diagrams, it would appear that the object to be sought is a device of such character that when the distribution of the load in a cart, or the haulage resistances of a roadway, shall permit the vehicle to take up and carry on its wheels a part of the weight of the horse, this distribution shall take place of itself. When, on the other hand, on ascending grades, or where the effort of hauling may demand an increase of downward pressure and an increase in the lever

arm with which the weight of the animal gains mechanical advantage over the resistance, then this other distribution and adjustment shall as automatically take place.

*Mr. John G. Shortall.**—I am naturally greatly interested in this subject, in behalf of the horse—not in behalf of the money-maker. I am so deeply impressed with the value of the suggestions of Mr. Brigg that I should much deplore having this discussion or proposition end here. I would like to have it transferred to a still larger audience—not so scientific, perhaps, but an audience that will take it up in a practical way, if possible, in addition to the scientific way. With that end in view, sir, I would like to make a motion, if this body will entertain it, that Mr. Brigg be requested at his own convenience in the near future to repeat this address, together with such matter added thereto as he has not been able from lack of time now to present, with the view of promoting the benefit that is contemplated to animals in the scientific proposition underlying this paper.†

Professor Hele-Shaw.‡—The invention of Mr. Brigg has, it seems to me, two aspects, the scientific and the practical. The scientific aspect is a simple one, although, when I first heard of the invention, which was some years ago, thinking it was the idea of another searcher after perpetual motion, I went to hear Mr. Brigg demonstrate the idea, but I was convinced from what he said that he was on the right track, and that his attachment was a really scientific device.

It often happens, that the inventor knows all about a thing and other people cannot, at first, understand it. Now, this is the way in which I explained his idea to myself. If you put upon an ordinary weighing balance, with pointers, a piece of wood, which we will call the tractor, and upon another you put another piece of wood, which we will call the vehicle, and if you attach a strip of india-rubber horizontally between the two, and pull, no effect takes place. Now, if you unhook one end and hook it across at an angle, then pull, you will notice that one pointer goes down and the other up, the weight is put upon the vehicle and taken off the tractor. You then unhook the india-rubber and hook it in the opposite way, and you will notice just the opposite result.

* President of the Illinois Humane Society.

† This motion was duly seconded and carried.

‡ Of Liverpool, England.

That, it seems to me, is the first idea of Mr. Brigg, to obtain some contrivance, without the hooking and unhooking, by which he could put the load upon the animal and take it off, or *vice-versa*, as and when required. And he does not limit himself to an animal, for he is bold enough to attack locomotive engineers and say they do not harness the locomotive properly to the train. He proposes to relieve the legs of the animal of part of their load when traveling down slight gradients and upon level roads. That is to say, that as the animal requires less friction on the ground, or as the vehicle requires less traction, the attachment shall, automatically, make the necessary transfer of weight to, or from, the horse's feet.

Here is an example of the transferrence of weight from one pair of the horse's legs to the other. If you take a single block and put it upon these two scales, and if you will pull you will notice that on one scale the load is increased and on the other the load is diminished. This is an experiment which any one might try for himself. Now, Mr. Brigg, as it seems to me, has this idea as well, that a horse rests on two pair of legs, and that when the horse is pulling he will pull off his front legs—a thing which I never noticed until I saw Mr. Brigg illustrate it several years ago, and now it is so simple that it seems a wonder that these things were never yet brought prominently forward.

Now, without giving you a lecture, which was far from my intention, I may say to you that Mr. Brigg's attachment seems to me to accomplish these things which I have endeavored to make clear. I happened to be in the Transportation Building at the Exposition the other day, and there I saw Mr. Brigg's vehicles, and I observed that, since I last saw him, he has considerably improved his method of attachment.

There are at least one hundred and fifty of these things already in use in the city of Liverpool, adopted by the most prominent firms, and I hope to see them adopted in every city in the world where horses are used in hauling heavy loads. When the horse begins to pull, and exercises an effort, a spring, which is partly carrying the horse, is overcome, and the downward pull on the horse more than overcomes this upward pull, and the horse gets the necessary grip.

I have just one word more to add, concerning the practical side, and that is, What has the horse to say to this? The carter has very little to say, for if you ask him he will say he "don't

know what it is," that it is some newfangled idea that his employer has put on, and he doesn't know what good it does; but the horse knows. The only case I know of in which a horse has expressed an opinion on this kind of question I came across the other day. I read an account of a colliery where they had tracks laid by which a horse pulled a car up the hill, and on going down the hill there was a little platform on one end of the car on which the horse was carried. He had been taught to step up on that platform and the car was let run down hill under the control of a brake. I asked the man who had charge of that arrangement whether it worked well. He said, "Yes, but the only objection we have to it is that sometimes on coming up the hill the horse wants to turn around and get in at the back." I think that shows as plainly as anything can that the horse does know what he feels most satisfactory. This is an invention which has occupied Mr. Brigg many years. I am located at Liverpool, where they have many fine draft-horses. A friend of mine who owns several fine animals adopted this arrangement, and he has nothing but praise to say of it.

I shall certainly continue to watch this subject, and I hope that some day Mr. Brigg will publish a history of the evolution of this contrivance, and of the various forms through which it has passed, as this would be an interesting contribution to the history of inventions.

Mr. Brigg.—The remarks of the gentlemen who first spoke were full of force, and if thoroughly investigated by you engineers I think you will find that what they state is perfectly true.

With regard to the remarks of Professor Shaw, wherein he says that the advantage of the attachment is not one perhaps that will give an immediate advantage and show the force of my claim, I think he is a little bit mistaken. I say it is a moral impossibility for a horse to be yoked to that attachment without getting a direct advantage from the very moment he is put in to the moment he is taken out, no matter whether he be walking, running, galloping, or standing still. It makes no difference, whatever he is doing he cannot exist in those shafts yoked with the new attachment without getting a *direct* advantage; it will enable the horse to travel further and to do more work than he could possibly do without it. If any gentleman here will put himself into the attachment and try the experiment for himself, he will find that of two men, each of equal power physically, the

one yoked to this attachment will outlast the other, no matter whether the experiment be tried in racing or in transporting loads. I think, perhaps, that will be a satisfactory answer as to its immediate advantage to the horse.

I may be pardoned a reference possible at the time of preparing the paper for final transmittal to press, but impossible at its first reading. The Judges of Group 83 of the Department of Transportation at the Columbian Exposition have felt themselves justified in according a special diploma, with its medal, to the exhibit of hauling attachments which I had made, constituting the device thereby one deserving the highest consideration. But not only so, if I may be permitted to quote their official comment, they say further, over their individual signatures, that the Brigg attachment is "an apparatus of excellent mechanical construction, based on true scientific principles, admirably adapted to the intended purpose of greatly reducing the draft of vehicles, especially those carrying freight; materially lessening the unnatural strain on horses and other animals, in hauling heavy loads by the primitive methods in general use. It seems to us, in a matter of this kind, which is so great an improvement in saving strength to beasts of burden, that the law should compel its adoption on all vehicles that carry heavy loads." I need not say that the approval of experts in this form is most gratifying to me.

DXLV.*

COMPRESSION AS A FACTOR IN STEAM-ENGINE ECONOMY.

BY FRANK H. BALL, NEW YORK CITY.

(Member of the Society.)

THIS paper is intended, first, to attack the theory that the most economical compression curve is one which fills the clearance space to initial pressure; second, to point out certain relations which the writer thinks should exist between the expansion curve and the compression curve, so that for any given point of cut-off the point of exhaust closure corresponding in efficiency may be known by inference.

Let Figs. 365, 366, and 367 represent theoretical diagrams, produced by Mariotte's law, which is considered sufficiently accurate in this case, as the diagrams will not be used for accurate measurements, but simply to illustrate a theory.

Let these diagrams be supposed to have been produced by an engine with 10% clearance, represented by the distance from *A* to *E*, and the vacuum line being *V V*.

In the diagram represented by Fig. 365, cut-off takes place at about $\frac{1}{3}$ stroke, and expansion is carried to the atmospheric line or the line of back pressure, thus preventing any waste by free expansion when exhaust takes place.

Compression is also made to just fill the clearance space to boiler pressure, leaving no waste room to be filled from the boiler.

Disregarding engine friction, and considering only the work indicated in the cylinder, this diagram would correspond to the highest efficiency of this engine if there were no loss by cylinder condensation. But it is well known that a considerably later cut off than $\frac{1}{3}$ stroke is more economical, notwithstanding the consequent waste by free expansion at exhaust, and the reason must be found in the fact that cylinder condensation is so nearly

* Presented at the Chicago meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

a fixed amount per stroke, that by increasing the power developed at each stroke the loss becomes relatively smaller.

Referring to Fig. 366, suppose the diagram *AHKCD* to have been produced by the same engine cutting off at ¼ stroke, which for the purpose of illustration will be assumed to be the most

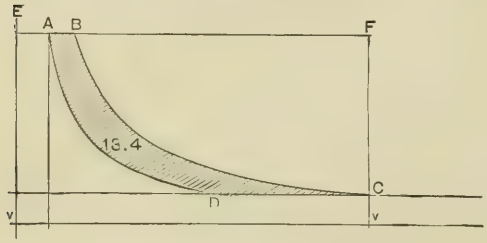


Fig. 365.

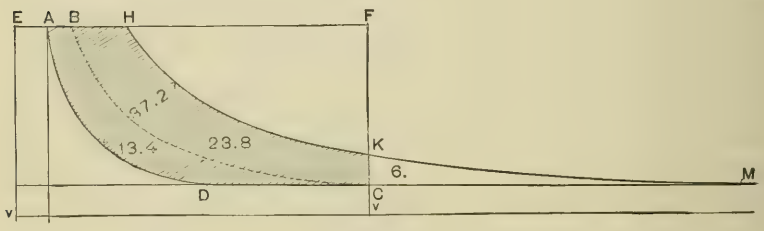


Fig. 366.

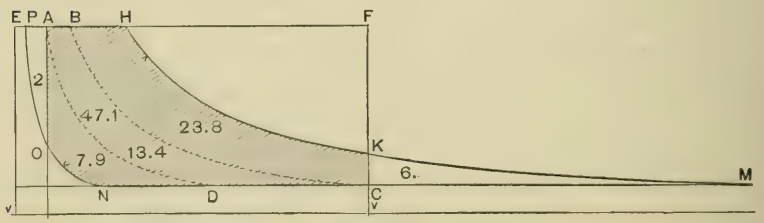


Fig. 367.

economical point of cut-off, although the logic of what is to follow would apply equally well to any other point of cut-off.

Comparing this diagram with Fig. 365, we find that by the later cut-off the mean effective pressure has been increased from 13.4 lbs. at $\frac{1}{15}$ cut-off to 37.2 lbs. at ¼ cut off, and the power thereby developed being nearly three times as great, the loss per horse-power by cylinder condensation has been greatly reduced, notwithstanding the considerable waste at exhaust due to throwing away steam only partially expanded.

Now if it be true that starting with the theoretically perfect diagram *ABCD*, it is economy to increase its area along the expansion curve up to a point where a considerable waste by free expansion occurs at exhaust, it must follow that it will be economy to add something to the area of the diagram along the compression curve also, and if *B* is not the most economical point of cut-off, it may be safely assumed that the point of exhaust closure *D* is equally faulty.

As before stated, one of the objects of this paper is to point out what seems to the writer a logical method of determining the compression curve which shall correspond in economy of steam with any given expansion curve.

Referring again to Fig. 366, suppose the expansion curve be continued from K to *M*, where it intersects the atmospheric line.*

The useful work added to the diagram *ABCD* by changing the point of cut-off from *B* to *H*, is represented by the area of the diagram *HKCB*, amounting to 23.8 lbs. M. E. P., and the work thrown away by free expansion at exhaust is represented by the area of diagram *KMC*, which measures 6 lbs. M. E. P.

With points of cut-off later than *H*, the curve *KM* increases rapidly in length by the removal of *M* along the atmospheric line, and the curve *HK* shortens by approaching the angle *F*, so that the area of the diagram of waste *KMC* increases very rapidly compared with the increase of the useful diagram *BHKC*.

The writer believes that what is true in regard to the expansion curve is equally true of the compression curve.

Referring to Fig. 367, if instead of the compression curve *DA*, the curve *NO* be substituted, the total area of effective diagram *AHKCD* will have been increased by the area of *ADNO*, equal to 7.9 lbs. M. E. P., so that the original diagram *ABCD*, with a M. E. P. of 13.4, has been increased by 23.8 lbs. M. E. P. along the expansion curve, and 7.9 M. E. P. along the compression curve.

The waste occasioned by the small compression *NO* is due to

* The diagram under consideration being a theoretic diagram, no distinction is made between the atmospheric line and the line of back pressure. With actual diagrams, whether exhausting into atmosphere or into vacuum, the continuation of the back pressure line parallel to *VV* should be substituted for the atmospheric line, both in the construction of the theoretically perfect diagram *ABCD* and also in locating the point *M*.

free expansion of the steam from the boiler in entering the clearance space, and is measured by the area of diagram PAO, because the steam shut in by exhaust closure at N and compressed to O would, if compressed to boiler pressure, fill the clearance space only from E to P, and the space from P to A must be filled from the boiler.

Suppose this to have been done, and the admission valve to be closed at A. As the piston advances, AD will be the expansion curve, and with NOP will form the diagram $ADNOP$.

Of this diagram, the area of $ADNO$ is useful work on the piston, and PAO is free expansion in the clearance space.

The area of this diagram PAO bears about the same relation to the useful diagram $ADNO$ that the diagram of waste KMC bears to $BHKC$, and hence it is not unreasonable to suppose that if the most economical point of cut-off is at H, the curve NO will correspond to the highest economy of the engine, or at least will correspond to the efficiency of cutting off at H, because in both cases the useful work added along the respective curves is attended with about the same proportionate loss by free expansion.

Carefully conducted tests might develop the necessity of some slight modification of this theory, but in the absence of such data the writer will venture to suggest, in accordance with the foregoing, a general law for approximating the point of exhaust closure which shall correspond in economy of steam with any given point of cut-off.

This law may be stated as follows:

If in a given diagram any free expansion takes place at the terminal pressure, then compression should not rise to initial pressure, but the compression curve should be removed from the curve of full compression * a sufficient distance, so that the useful work thereby added to the diagram shall be accompanied with the same proportionate loss by free expansion that is found to accompany the work that has been added to the full expansion curve.†

---

* "Full compression" is here used to describe the curve which just reaches initial pressure within the vertical lines representing the piston travel, as DA, Fig. 365.

† The term "full expansion curve" is used to describe a continuous expansion curve, terminating on the line of back pressure within the limits of piston travel, as BC, Fig. 365.

In applying this law to the study of actual diagrams, first construct the full expansion curve, as *BC*, Fig. 365. This is best done by tracing it backward from *C*. Next construct the full compression curve, as *DA*, beginning for convenience at *A*. This will give the theoretically perfect diagram *ABCD*, located with proper relation to the actual diagram for the purpose of comparison.

Next continue the line of back pressure parallel to *VV* a sufficient distance to intersect the continuation of the actual expansion curve, as from *K* to *M*, Fig. 367.

Having done this, the diagrams *BHKCB* and *KMC* may each be measured and the ratio of their respective areas determined.

The compression curve *NOP* must then be so located that this ratio will apply to the respective areas of *ADNO* and *PAO*.

With this compression curve *NO*, located as described, we are ready to make comparison with the actual compression curve of the diagram under consideration.

In accordance with this law, it might also be said that whenever the area of any diagram exceeds the area of the theoretically perfect diagram *ABCD*, Fig. 365, then this excess of area should be found distributed along the expansion and compression curves in the proportions indicated by this law, and it necessarily follows that a fixed compression will therefore not give as high economy of steam under varying loads as a varying compression, and that the highest economy might be expected when both the point of cut-off and of exhaust closure vary in such a manner that the relation of the areas added along the expansion and compression curves of *ABCD* shall at all times conform to this law.

To further illustrate this subject, a series of five theoretic diagrams, Figs. 368 to 372, are herewith submitted, in which various points of cut-off are selected between $\frac{1}{15}$ and $\frac{1}{3}$ stroke, and compression curves corresponding to such expansion curves are shown.

From measurement of these diagrams, various curves are constructed on a chart, shown in Fig. 373.

Referring to this series of diagrams, the distance from *A* to *F* in each is made to represent the piston travel, and *AE* the clearance. The atmospheric line is *CD* and the vacuum *VV*.

In each of the diagrams of the series, except Fig. 368, a loss by free expansion occurs, and all, including Fig. 368, are accompanied

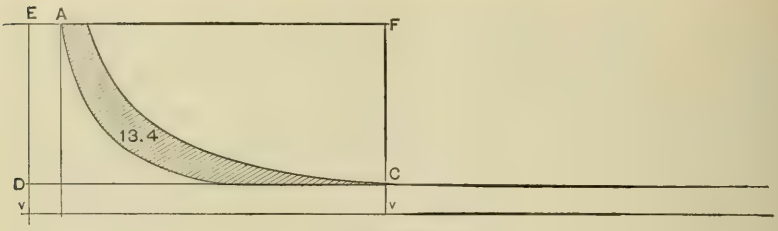


FIG. 368.

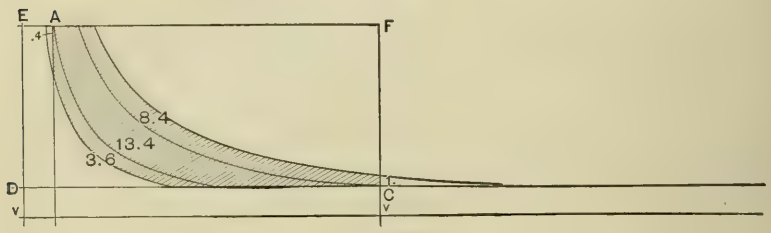


FIG. 369.

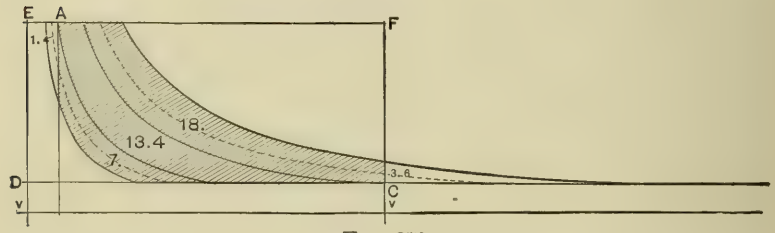


FIG. 370.

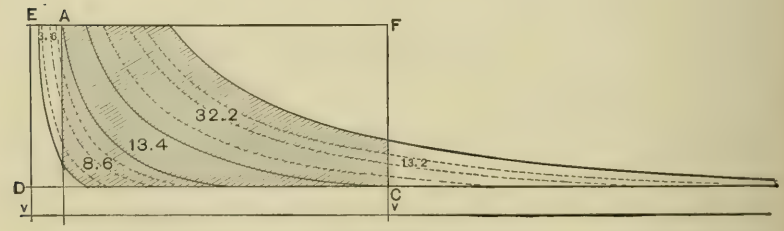


FIG. 371.

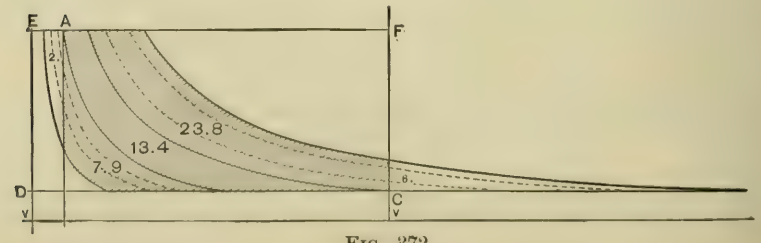


FIG. 372.

by a loss due to cylinder condensation which does not appear in the diagram.

This cylinder condensation is the difference between the steam accounted for by the indicator and that actually used by the engine, and may be expressed in pounds of feed-water or steam, or in area of diagram, or mean effective pressure.

The latter method will be adopted in this investigation.

Thus in Fig. 368, with a M. E. P. of 13.4 lbs., if the indicator only accounts for $\frac{4}{5}$ of the steam, the cylinder condensation may be expressed in pounds M. E. P. by $\frac{13.4}{4} = 3.3$ M. E. P.

With this method of measurement, the whole area of the diagram must be used to express the steam accounted for by the indicator, and if it extends beyond the limit of piston travel, as in Figs. 369 to 372, it must be reduced to M. E. P. for the piston travel. Thus in Fig. 369 the M. E. P. of the useful diagram is 8.4 + 13.4 + 3.6 = 25.4, and the diagram of free expansion or waste, .4 + 1 = 1.4 M. E. P.

The total M. E. P. which may be used as representing the steam accounted for by the indicator is therefore 25.4 + 1.4 = 26.8.

In all these diagrams the areas enclosed by heavy lines are indicated by figures which express the pounds M. E. P. in each case.

With the series thus arranged any desired combination of the expansion and compression curves may be made.

Two such combinations are used in constructing the curves of Fig. 373, one where the compression curve of Fig. 368 remains constant through the series, and the other where the compression curve progresses through the whole series in harmony with the law that has been heretofore suggested. Fig. 373 represents the curves of efficiency produced by these two combinations under the following conditions:

(1) The curves AB and AC assume that the loss by cylinder condensation is directly in proportion to the M. E. P. of the diagram and is $\frac{1}{5}$ of the total steam in every case.

(2) DE and DC assume that the cylinder condensation is a constant quantity equal in amount to $\frac{1}{5}$ of the total steam used at $\frac{1}{4}$ cut-off.

(3) FB and FH assume the same cylinder condensation as in the latter case, and the curves show the net efficiency of the

engine where the loss by friction is also a constant quantity equal to 8% of the capacity of the engine at ¼ cut-off.

Each diagram of the series is used to establish one point on each of the curves of Fig. 373.

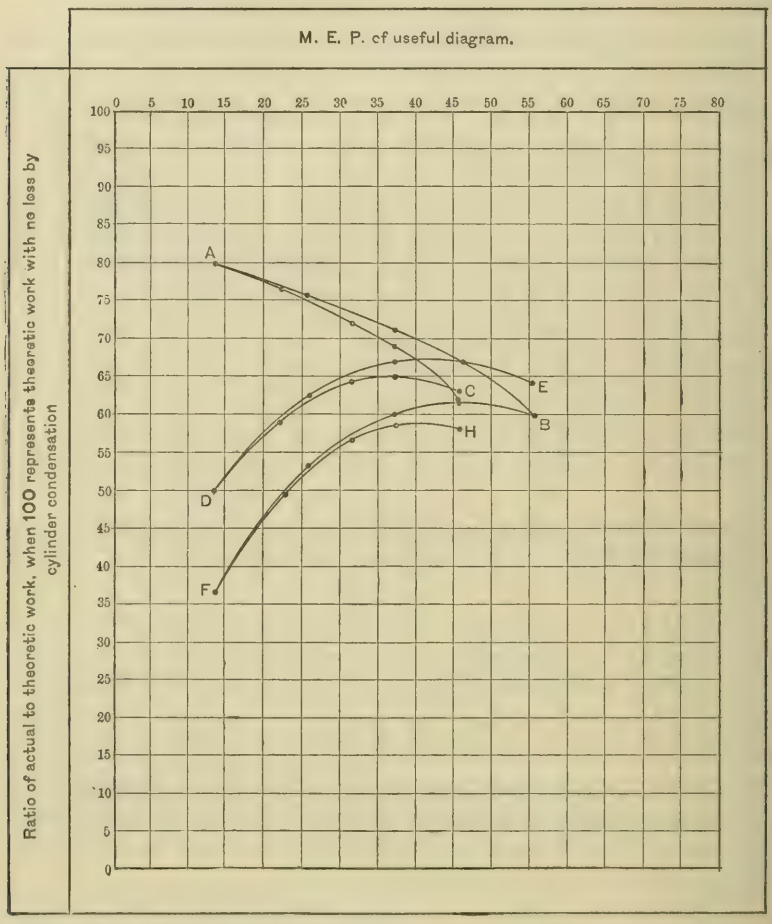

M. E. P. of useful diagram.
Ratio of actual to theoretic work, when 100 represents theoretic work with no loss by cylinder condensation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
A
B
C
D
E
F
H

FIG. 373.

Thus *A* on Fig. 373 is established from Fig. 368 as follows:

M. E. P. = 13.4 and is measured on abscissa.

Cylinder condensation being assumed to be ⅙ the total steam as stated, then the useful work in M. E. P. of diagram is only ⅚ or 80% of the theoretic work, and is measured on ordinates.

The next point in curve AB is obtained from Fig. 369 as follows:

Total M. E. P. of diagram Fig. 5 = 8.4 + 13.4 + 3.6 + .4 + 1 =	26.8 M. E. P.
Condensation is $\frac{1}{4}$ × 26.8 M. E. P. =	6.7 "
Total steam used, expressed in M. E. P. as follows:	
Accounted for by the indicator, 26.8 } =	33.5
Cylinder condensation, 6.7 }	
M. E. P. of useful diagram, 8.4 + 13.4 + 3.6 =	25.4

Efficiency, $\frac{25.4}{33.5} = 75.8\%$

The second point in curve AB is therefore 25.4 M. E. P. and 75.8 efficiency.

The points on curve AC are obtained in the same manner, but in every case the compression curve of Fig. 368 is used, and no measurements beyond that curve are included.

The curves from D and F are produced in a similar manner, except that the loss by condensation in the first, and condensation and friction in the last, are assumed to be a constant quantity, as already stated.

Whatever may be the truth as to the loss by cylinder condensation, it is evident that the best result under any circumstances is with the variable compression, as the upper curve of each pair is obtained in that way, while the lower curve is produced by constant compression. It will be found also that any compression curve which does not conform to the law under which these were made, will produce a curve of lower efficiency than the upper one of each pair in Fig. 373.

The condensation assumed by the curves from A, Fig. 373, is evidently far from the truth, as it shows the highest efficiency of the engine at the earliest point of cut-off.

These curves from A have been constructed to show that even with this extreme and impossible condition the varying compression shows even a greater gain than with the condensation which probably exists in practice.

The point D is probably a little too low, as cylinder condensation is not probably a constant quantity, and the true curve would therefore begin a little above D.

Following the curve DE, it will be seen that the highest efficiency is between 40 and 45 lbs. M. E. P., while with the fixed compression of DC the best result is between 35 and 40 lbs. M E. P., and the difference at 40 lbs. M. E.P. is about 3% of 65, or nearly 5% of the work done.

The curves from F show the wastefulness of light loads when the net work is measured as delivered to the belt, and it also shows the highest efficiency to be with nearly 5 lbs. higher M. E. P. than when the indicated power only is considered.

The study of diagrams by this method of measuring the waste occasioned by free expansion suggests a possible application of the same method to diagrams from compound engines, both in regard to comparisons in each cylinder between the expansion and compression curves, and also comparisons between the various cylinders as to *all* free expansion losses.

This is, however, foreign to the subject of this paper, and will be left for another paper, which the writer hopes to present at the next meeting of this Society.

DISCUSSION.

Mr. A. K. Mansfield.—It may be of interest to call attention here to a rough investigation which I have made as to the relation of clearance and compression to economy in a compound engine, under conditions very often met with in practice.

The figure herewith (Fig. 374) was reproduced from a diagram drawn as large as could conveniently be measured with a planimeter. Accuracy was sought in laying out the lines and in taking the areas. The upper portion of the diagram represents various high-pressure cards, the initial pressure of all being 110 lbs. above atmosphere, and cut-off three-tenths. The lower portion represents corresponding low-pressure cards, the back-pressure being taken at 11 lbs. below atmosphere, and the receiver pressure such that the work in cylinders is approximately the same. The ratio of cylinders is taken at three to one, and the point of cut-off in the low-pressure cylinder is found from the consideration that the volume of fluid present, times the pressure, is the same as at cut-off in the high-pressure cylinder. The measure of this volume is the horizontal line from point of cut-off to the corresponding compression line, whether this line falls within or outside the card. The lower cards are drawn to three times the vertical scale of the upper.

First, three sets of expansion and compression curves were drawn, corresponding to no clearance, 2% clearance, and 10% clearance, compression in each case extending to initial pressure. Corresponding areas of the two cards were then added together, and their sums found to be to each other as 100 to 97.8 to 90.1,

indicating that under the conditions named the efficiency of the steam is about 2% less with 2% clearance in each cylinder than with no clearance, and about 10% less with 10% clearance in each cylinder than with no clearance ; also that about 8% efficiency is lost in increasing clearance in each cylinder from 2% to 10%.

Next, compression curves were drawn, as shown, corresponding to one-half as great compression as before. In the upper diagram the same expansion lines are used in taking areas as before, but in the lower diagram new expansion lines, *a* and *b*, are drawn from

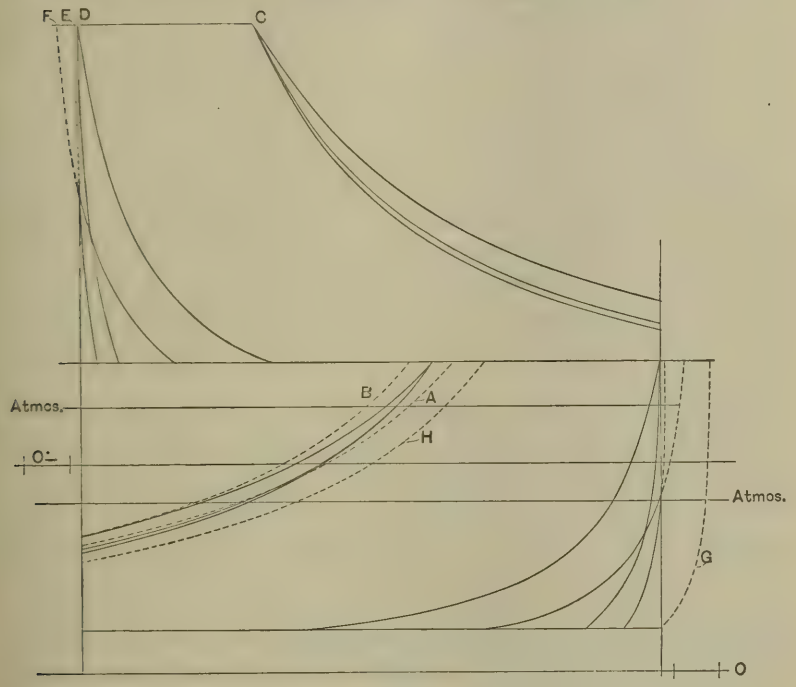


Fig. 374.

points of cut-off determined as before stated, it being borne in mind that the volume of steam admitted to the high-pressure cylinder is now measured, in case of 2% clearance, by the line *ce*, and in case of 10% by the line *cp*. Adding the areas corresponding to 2% and 10% clearance as before, and reducing the sums in the ratios of *cd* to *ce* and *cd* to *cf* respectively, it is found that the efficiency of the fluid remains practically the same as before. No difference worth considering results.

This seems to show that under the conditions assumed we have no reason to expect greater economy to result from a high degree of compression than from a low degree, thus confirming, to some extent, the theory of Mr. Ball.

As a matter of further interest, it was assumed that the fluid was compressed to initial pressure in the high-pressure cylinder of 10% clearance, and that no compression took place in the low-pressure, but that the exhaust valve closed exactly at the end of the stroke, a condition not impracticable in a tandem construction. The corresponding compression and expansion curves were then drawn and the efficiency of the fluid determined as before. It was found to be represented by the figure 92.7, which, compared with the former figure, 90.1, indicates a possible gain of nearly 3% in favor of "cushioning" entirely in the high-pressure cylinder, both cylinders having 10% clearance.

Further, by combining the card of the high-pressure cylinder having 2% clearance with that of the low-pressure cylinder having 10% clearance, and *vice versa*, it was found that about 2% greater efficiency is obtained by the former than by the latter arrangement; that is, it seems to be somewhat less objectionable to have larger clearance in the low-pressure cylinder than in the high-pressure.

Prof. D. S. Jacobus.—We have one of Mr. Ball's engines erected at the Stevens Institute, and we intend to go into this matter and test it by actual experiment. There are already several theories in regard to the best point at which to start the compression, and the only way to settle which of these is correct is by actual experiment, because any theory which handles the problem correctly has to include the effect of cylinder condensation, and the moment we include this we have to make an experiment. It is, therefore, just as easy, and more exact, to determine experimentally where the compression curve shall be placed for the best efficiency, as to determine the cylinder condensation for various points of cut-off, and then calculate the position of the compression curve. Mr. Ball is now constructing special valves and expansion plates whereby the compression curve can be altered for a given point of cut-off in the engine now at the institute, and after that is done we are going to make thorough experiments and determine how well his theory applies.

Prof. John H. Barr.—This is a subject upon which I did some work about two years ago, and I concluded from what I saw at

that time that there were some points concerning compression which had not been commonly recognized. I must confess, however, that I cannot quite see the logic, from the paper before us, of the double-acting law. I shall not attempt at this time to discuss the paper fully, but there is one point that occurred to me in my brief examination of the subject, which I would like to mention. It is a consideration of the mechanical effect alone.

Now suppose the engine is running at the cut-off to give the maximum efficiency. It is necessary to have this cut-off vary to meet changes in load and steam pressure. Here is the point on which I wish to speak this morning. If we close the exhaust at the point *b* (Fig. 375), we do so at the expense of an amount

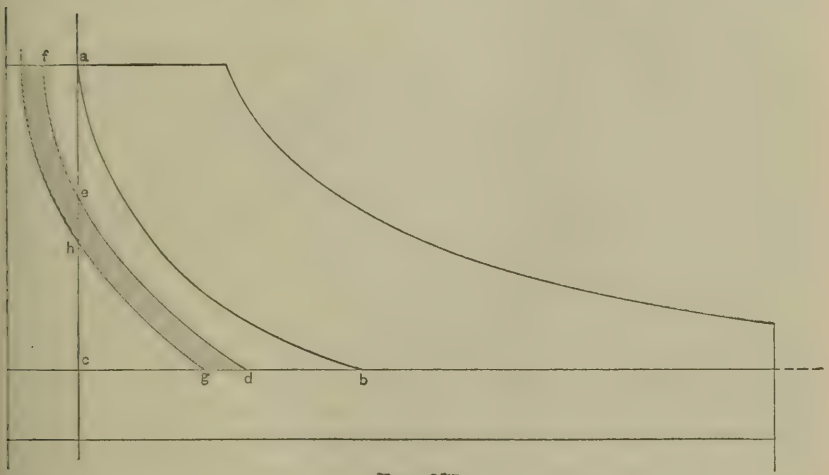


FIG. 375.

of indicated work represented by *abc*. If we close the exhaust at *d*, compressing up to the point *e*, we gain an amount of indicated work equal to *abde* over the preceding case. This is at a loss, as Mr. Ball shows us, of *fea*. With exhaust closure at *g*, compressing up to *h*, we see that the total gain of indicated work is *abgh*, and the loss is *ahi*. As the exhaust closure occurs later in the stroke the indicated work is increased; but the clearance loss is increased also. It will be seen that the increment of gain in indicated work, *edgh*, due to changing the exhaust closure from *d* to *g*, decreases relative to the corresponding increment of clearance loss, *efih*, as exhaust closure occurs later in the stroke.

There is, evidently, a point at which the increment of gain in indicated work equals the increment of clearance loss, and it would seem that, *mechanically*, this is the point at which to fix exhaust closure. This is but one element in the problem, and as it neglects the important effect of compression upon cylinder condensation, it is not offered as a solution of the problem.

Professor Jacobus.—I would like to ask Professor Barr whether the point at which economical compression should begin, according to his reasoning, depends upon the point of cut-off.

Professor Barr.—In this consideration it does not. It depends simply upon the back-pressure and clearance.

Professor Jacobus.—Then the solution is not complete, because the point at which the compression should begin varies for different points of cut-off.

Mr. E. T. Sederholm.—I would like to call attention to one thing, and that is, that in compressing to this extent, while we theoretically lose this amount of work, actually we do not lose nearly as much, because in compressing to any extent we necessarily reduce the friction of the engine. The momentum of all the reciprocating parts has to be used up in some way, either by pressure on the journals, or by a steam cushion. Therefore, I think that in figuring up this loss of work we also have to take account of the fact that the greatest part of the compression is really produced at no additional cost. That is, there is little or no additional power required to compensate for what the engine theoretically loses through compression. While a difference may exist between the location of the most economical compression curve and the curve which the author calls "full compression curve," the curve representing the highest actual economy would be more like this [draws a compression curve on the blackboard nearly as high as full compression]. But, as one speaker said this morning, this question can only be decided after accurate trials, and it seems to me that it is very necessary at this time that we should know which is really the best compression curve.

Mr. Frank H. Ball.—Mr. Mansfield gives us some very interesting figures obtained from hypothetical diagrams, and some of his conclusions (notably that in the closing paragraph) are quite contrary to generally accepted ideas; but these facts and figures can hardly be considered as a discussion of my paper, because cylinder condensation is neglected.

My theory is based on the assumption that there is a loss by

cylinder condensation, and that the loss is not in proportion to the work done, but is approximately a constant amount per stroke; and in seeking the largest amount of work per stroke on which to distribute this cylinder condensation loss, both the expansion and compression curves must conform to a certain law. I have not said anything about the effect of large clearance or small clearance, but have simply pointed out a law for obtaining the greatest M. E. P. with the least proportionate loss by free expansion, and have applied the law to a series of theoretic diagrams.

Professor Jacobus recognizes the fact that cylinder condensation is the starting point from which to discuss this subject, and the tests which he and Professor Denton have undertaken at the Stevens Institute will furnish valuable data, which, it is to be hoped, they will give to the Society at the next meeting.

Professor Barr, like Mr. Mansfield, disregards cylinder condensation; but even as a geometrical proposition, if it is required to obtain a given area of diagram within the limits of piston travel with the least possible loss by free expansion, it then becomes necessary to extend both the expansion and compression curves beyond the piston travel, and measure these free expansion losses. Professor Barr has only considered the free expansion loss on the compression curve, and does not take into account the loss at terminal pressure.

Mr. Sederholm's remarks in regard to friction are very pertinent. Friction and condensation are presumably constant, or approximately so, and that is the theory on which this paper is based. It is, no doubt, a mistake to load an engine with a view to obtaining the greatest economy per *indicated horse-power*, thus disregarding the net horse-power delivered to the belt. The curves of efficiency, shown in Fig. 373 of the paper under discussion, show that the best economy per *net horse-power* is with a greater load than that which shows the best performance per *indicated horse-power*.

In closing, I will say that you will notice I have not given any geometrical method for locating the compression curve; I left this, hoping that some of our professional mathematicians would suggest some mathematical method for locating this curve in conformity to the law which has been stated.

DXLVI.*

PERFORMANCE OF STREET RAILWAY POWER PLANTS.

BY WM. A. PIKE AND T. W. HUGO.

(Members of the Society.)

No mechanic art has become so interwoven with our every-day existence as that of electric engineering. No branch of industry has grown, in so short a period of time, to the proportions now assumed by the practical applications of the developments of the science of electricity; and as a consequence the application has been in advance of the definite knowledge of the results of such application; in other words, the application has led the pace, and that being a fast one the engineer is now, almost breathless, endeavoring to catch up and find out just what he has been doing. He knows what he intended to do, and what results he ought to obtain, but as to how close to those results he has come under the different conditions of every-day practice he is very much at sea. Especially is this the fact in street railway practice, and it is to contribute a mite to the general knowledge box that this paper is presented, as embracing, possibly, as wide a scope and as extensive a field, under ordinary, every-day practice as has heretofore been made public. As will be seen, no particular piece of machinery was under criticism, no person's creation was on trial, the facts, and nothing but the facts, being sought, in order (1) to ascertain the cost of motive power per car mile (*a*) as furnished by the tri-cylinder condensing Corliss engines at Power House No. 1, Minneapolis; (*b*) as furnished by the tri-cylinder condensing engines at the Hill Street Power House, St. Paul; (*c*) as furnished by the two-cylinder non-condensing Westinghouse engines at the Thirty-first Street Power House, Minneapolis.

(2) To obtain data as to the economy of the boilers used.

(3) To obtain data as to the relative value of crude petroleum and coal as fuel.

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

(4) To compare the cost of furnishing power by large tri-cylinder condensing engines and small Westinghouse two-cylinder non-condensing engines, or concentrated *vs.* subdivided power. Incidentally many minor questions came up which will appear in the body of this paper.

The tests which are the basis of this paper were made at the instance of Mr. Thomas Lowry, President of the Twin City Rapid Transit Co, Minneapolis and St. Paul, Minn., on the various plants of the company.

The tests at Power House No. 1, Minneapolis, and the principal tests at the Hill Street Station, St. Paul, were made under the joint supervision of Messrs. Wm. A. Pike, of Minneapolis, T. W. Hugo, of Duluth, members of the American Society of Mechanical Engineers, and Mr. Aid Collins, agent of the Hartford Boiler Insurance Co., of Minneapolis; and the test using screenings for fuel at St. Paul, and the tests at the Thirty-first Street Power House, Minneapolis, were under the direction of Mr. Pike alone. It is perhaps proper to state that the first proposition for these tests was made to the Hartford Boiler Insurance Co., but as this company did not care to undertake the work it was arranged for as stated above. Acknowledgment is hereby made of the courtesy of Mr. Thomas Lowry in allowing the publication of these results, and of the very efficient services of a large number of engineering students from the University of Minnesota, who constituted the greater part of the corps of observers.

It might be interesting to describe many of the details, such as the commissary department necessary to provide for supplying the needs of the thirty persons engaged in this particular work. None of the regular employees took any part in anything connected with the extra work of the tests; they merely kept the plant in its usual working conditions. Many features required considerable thought, which in tests on a small scale demand very little consideration, but it is believed that the technical features alone will comprise a bulky paper, and some of the incidents may form the subject matter for future papers. Although much care and attention were given to every detail, yet the pump which causes trouble when most urgently needed, the joint and the valve which leak on such occasions but at no other time, the indicator spring which breaks, the cord which stretches, the fellow who lets the indicator cards fall into the oil tank, and the Kodak fiend were all on duty, and the usual makeshifts and

improvisations were called into service, and the genius of the operators taxed to keep things moving, and it is believed that the results obtained are correct and worthy of study.

Test No. 1, Minneapolis, March 5, 1893.

Power House No. 1 contains the plant from which was obtained the power used during the first series of tests; two tri-cylinder condensing engines of the design of the E. P. Allis Co., of Milwaukee, Wis., together with a single cylinder engine of the same make, five Babcock & Wilcox and two Stirling water tube boilers, 16 Edison railway generators of 175 kilowatts capacity, and 2 of 89 kilowatts, constitute the motive machinery. Each of the two tri-cylinder engines was belted to a line shaft through which the power was transmitted to the generators, and also to a 100-light Excelsior, new style, arc dynamo, furnishing lights as needed.

The system of transmission is the single trolley overhead system, operating eighteen car lines with a total of about eighty miles of track, including that portion of the inter-urban line connecting Minneapolis and St. Paul from Minneapolis to Midway, a distance of about four miles. Motors ranging from 15 to 30 H.P. of the Sprague and the T. H. type are used on the cars.

PRECAUTIONS TO INSURE ACCURACY.

(1) Previous to the tests all steam-gauges used were tested by comparison with a mercury column, and then either corrected, or a table of errors made from which true pressures were obtained.

(2) All indicator springs were tested under steam-pressure by comparison with a correct gauge, and either found correct or their numbers changed to correspond with true pressures.

(3) All thermometers were tested by comparison with boiling and freezing points, and by comparison with a standard thermometer.

(4) All scales used were adjusted and certified to by Fairbanks, Morse & Co.

(5) The pyrometers were compared with a correct thermometer in a smoke flue, and a table of corrections made.

(6) The water meter used for measuring the injection water was calibrated by weighing the water actually discharged and comparing it with its readings.

METHODS ADOPTED IN CONDUCTING THE TESTS.

During the whole time occupied in the tests all observations necessary to obtain the desired data were taken every stated ten minutes, an electric gong operated by the timekeeper giving the signal to all, except in the case of the ammeter readings, which were taken every fifteen seconds; the current was all passed through two ammeters so regulated that an equal amount of current went through each. The voltage was practically constant, and was also noted.

FIG. 376.

All water and fuel oil were weighed accurately before passing to the boilers. Two large wooden tanks were elevated on scales placed on platforms. The supply for those tanks were provided with a branch pipe and stop-valve for each tank, and by a stop-valve and pipe from the bottom, each discharged into the iron receiving tank. This arrangement is shown in Fig. 376.

The feed water was pumped to the weighing tanks by a 7 x 10 x 10 inch duplex steam-pump, and taken from the iron receiving tank by a second steam-pump of the same size and sent to the boilers.

The fuel oil was pumped by a $4\frac{1}{2} \times 2\frac{3}{4} \times 4$ inch duplex pump into two iron tanks placed on scales elevated on a platform from which, by discharge pipes at the bottom and stop-valves, the oil was drawn off into another iron tank, also elevated on a platform, from whence by gravity it was conducted to the atomizers that supplied the furnaces.

This arrangement of tanks is shown in the background of Fig. 377.

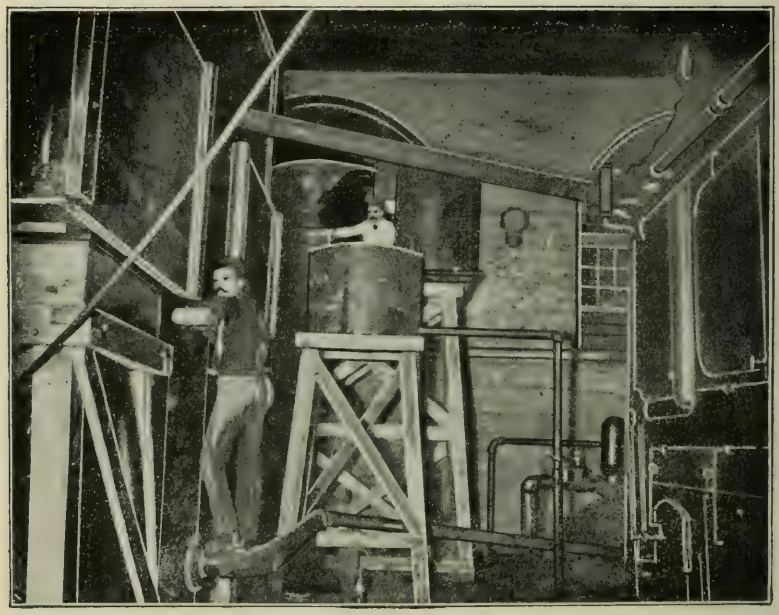


Fig. 377.

During ordinary running but one of each of the above-mentioned pumps is used, the other being held in reserve.

During the first test the Babcock & Wilcox boilers Nos. 1, 2, 3, 4, 5, supplied steam for the two tri-cylinder engines exclusively, except that used for atomizing the fuel oil fed to the furnaces of those boilers, for which, however, a proper deduction is made.

To supply the steam for the condenser engines, feed and oil pumps, and for the heating system of the building, the Stirling boiler No. 2 was used, and a separate pump, $4\frac{1}{2} \times 2\frac{3}{4} \times 4$ inches, supplied it with feed water.

All possible outlets for either steam or water, except those necessary for furnishing steam to the engines and water to the boilers, were blanked off or known to be tight, except in one case hereafter noted.

Steam-engine indicators were attached to each end of each cylinder, the motion being received through a swinging pendulum as shown by Fig. 378, the cords being guided by a properly constructed arc fastened to this pendulum; and as in these tests twelve indicators were in some cases employed, and as it was

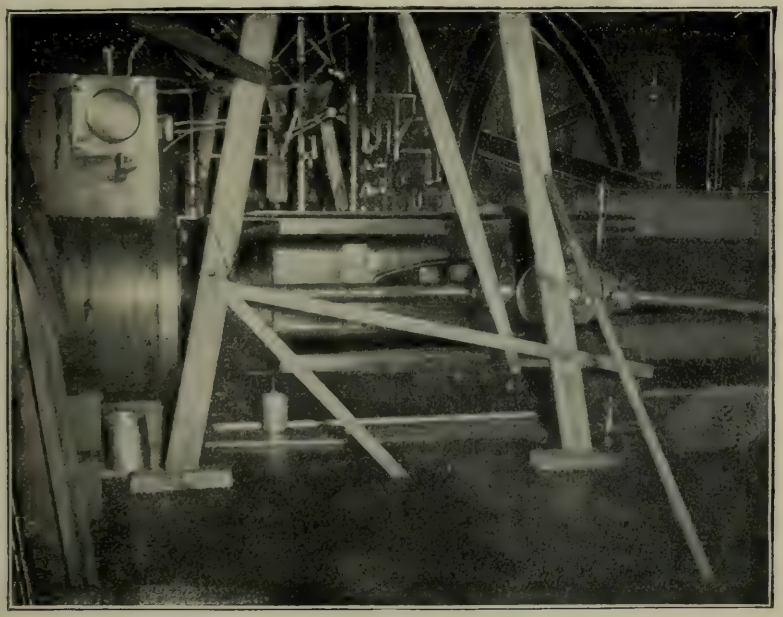


Fig. 378.

considered advisable to have the diagrams taken simultaneously, the following described electric attachment was devised, by means of which the pencils of all the instruments were moved up to their respective drums at the same instant.

In Fig. 379, M is an ordinary bell magnet of about one ohm resistance, attached by the clamp C to the indicator. The armature A is attached by the bar B to the pencil movement. The wires W form a circuit through which a current of about twelve amperes is passed, this current is obtained from the main line and reduced as above by passing through a resistance box. The twelve indicator attachments were connected in series and

were in the circuit between the controlling switch and the ground, thus preventing the possibility of "shocking" the observer when the switch was open.

The pencil is ordinarily kept away from the drum by means

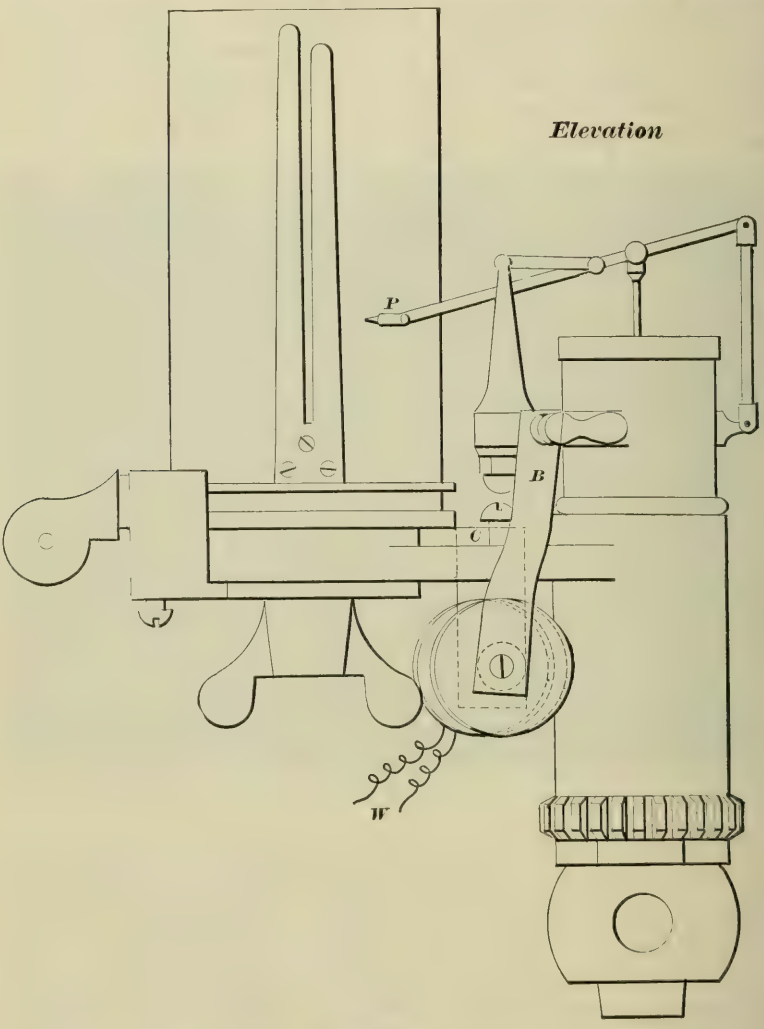


FIG. 379.

of a light spring. When, however, the switch is closed, the armature A, being drawn toward the magnet M, causes the pencil P to press against the paper on the drum. The amount of pressure is regulated by the set screw S.

On opening the switch, the armature is released and the spring withdraws the pencil from the drum.

It will be noticed, in Fig. 381, that in some cases the magnet was supported by a wooden stand, but it was found that the arrangement described above was more compact and less liable to derangement.

In addition, an indicator was attached to each of the condenser engines and diagrams taken at the usual stated periods, at the sound of the signal gong.

The water collected from steam-jackets and separators was weighed separately, as is more fully described hereafter.

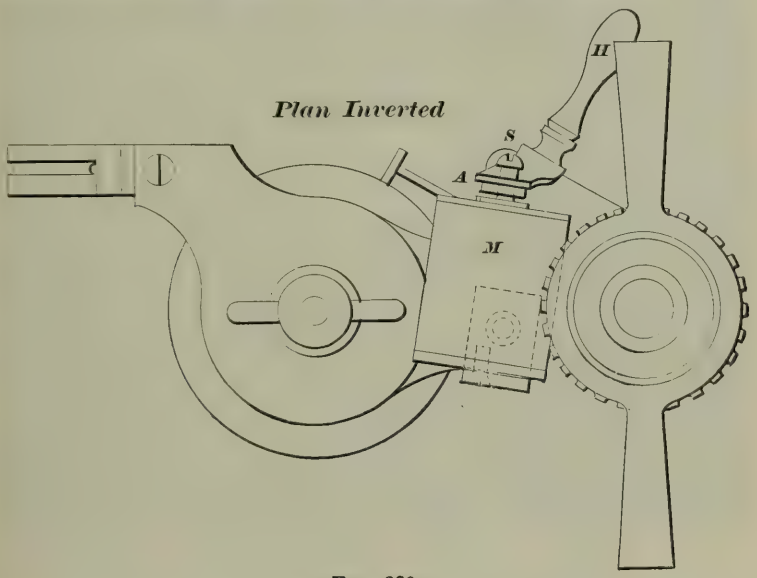


FIG. 380.

The revolutions of the engine were obtained from continuously recording revolution counters, and, in connection with boiler and receiver pressures, and vacuum gauge and barometric readings, were noted at each stated period of ten minutes. The arrangement of gauges, etc., is shown in Fig. 382.

At the stated periods the height of water and oil in the feeding tanks, and the height of water in the boilers, as shown by the glass water-gauge, was noted, so that if, by any accident, it became necessary to stop the test before the expiration of the expected time, the data of the entire test would not be lost, and by going back to the last stated period a general summing up

could be made covering the actual time of the test; also, these figures for each stated period are valuable as checks on final results.

Calorimeters of the barrel, separator, and throttling type for determining the percentage of moisture in the steam were attached to the main steam-pipe in the boiler room (Fig. 383); to the feed pipe of each engine just above the throttle valve (Figs. 384 and 385).

The pyrometers and draught gauge were inserted in the main

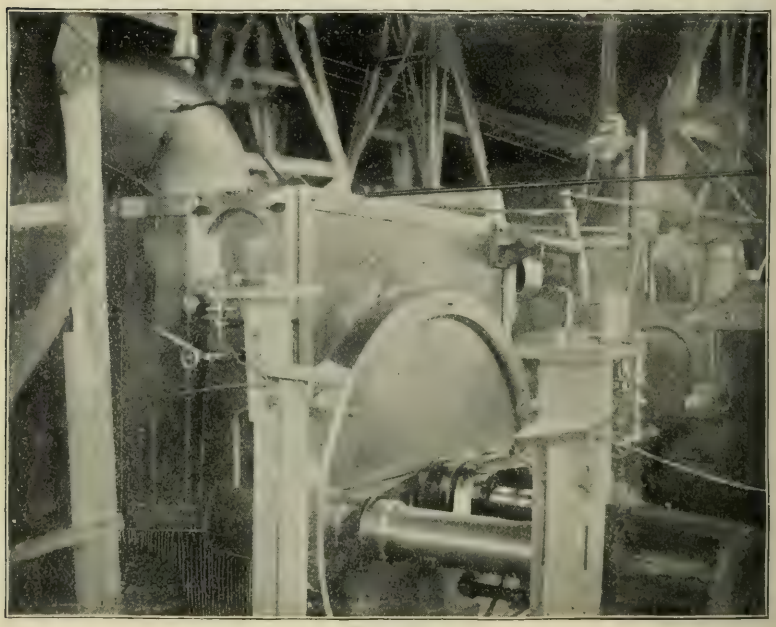


FIG. 381.

flue (Fig. 386), and a record kept, as well as of the steam-pressures and feed-water temperatures at the boiler.

Samples of the fuel oil used were taken for chemical analysis at suitable intervals.

On blanks furnished each street-car conductor was noted, every stated ten minutes:

(1) Whether moving or stopped.
(2) Number of passengers.
(3) Location of car.
(4) Whether car is lighted or not.

(See sample of conductor's record, Table No. 18.)

A record was kept of the number of lamps burning, and the

length of time in use at the different stations and other places, from which the power used for this purpose was calculated.

DIMENSIONS OF BOILERS.

Kind	Babcock & Wilcox
No. of head drums	2
Diam. of head drums	36 inches
Length of head drums	17 feet 3 inches
Diam. of water tubes	4 inches
No. of tubes: 144 main tubes	17 feet 9½ inches
No. of tubes: 16 tubes between headers and drum	7 feet 4 inches
16 headers	5 feet high x 6 inches wide
Mud drum	9 feet long, 18 inches diam.
Area of grate	71 square feet
Heating surface (figures from makers)	3,128 square feet
Ratio of grate to heating surface	1 : 44
Distance from grate to tubes	3 feet 8 inches at front, 2 feet 4 inches at bridge

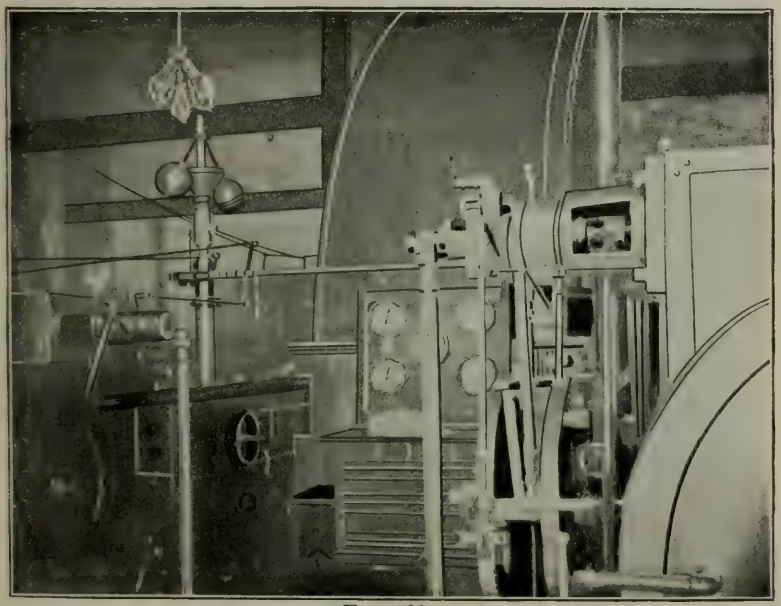


FIG. 382.

Each Babcock & Wilcox boiler has two steam-pipes, stated to be 5⅝ inches in diameter, and is 2 feet 4 inches long, connecting with an 8-inch pipe having two L's and one T, which connects with a 12-inch header. This header, after leaving boiler No. 5, connects with a 15⅜-inch main, running to separator No. 1. This main is 175 feet 2½ inches long, and after

making five turns connects with the separator at a point 2 feet 6 inches from the bottom, and one 10-inch branch is taken from the top of the separator and runs to engine No. 1, and from the opposite side of the separator, and 15 inches above the inlet, a $15\frac{3}{8}$-inch pipe runs to separator No. 2, 45 feet 9 inches distant.

The water collected in the separators and jackets is usually drawn therefrom by ordinary steam-traps and discharged into a tank from whence it is pumped to a receiver in the boiler room, where, after being mixed with sufficient overflow water from the condensers, it is used for feed water.

The pipe supplying jackets is $1\frac{1}{4}$ inches in diameter and is connected to a T in the branch steam-pipe 4 feet above the separator of the main steam-pipe.

The steam pipe from each separator to the engine is about 10 feet long and 10 inches diameter, with one turn, to a valve, then with four turns to the engine it is 8 inches diameter and $56\frac{1}{2}$ feet long.

Each of the Stirling boilers consists of :

Three drums at top, each $3\frac{1}{4}$ feet diameter and 11 feet 8 inches long.

One drum at bottom, $3\frac{1}{4}$ feet diameter and 11 feet 8 inches long.

Sixty oblique tubes connecting upper outside and lower drums, each tube $3\frac{1}{4}$ inches diameter, 12 feet long

Eighty inside tubes, $3\frac{1}{4}$ inches diameter, 14 feet long.

Eighty middle tubes, $3\frac{1}{4}$ inches diameter, 12 feet long.

Twenty tubes, $3\frac{1}{4}$ inches diameter, 3 feet 4 inches long, between drums Nos. 1 and 2: these are in the steam-space, superheating surface.

Twenty tubes, 3 feet 4 inches long; between Nos. 2 and 3, heating surface.

Forty tubes, 3 feet 8 inches long; between Nos. 2 and 3, superheating surface.

Total heating surface (figures from makers)	2,875.00 square feet
Total grate surface 6 feet 3 inches x 9 feet $11\frac{1}{2}$ inches	65.00 square feet
Ratio of heating to grate surface	44.25 : 1
Total superheating surface	165.5 square feet

The Stirling boilers have each one 8-inch steam-pipe 27 feet long, with two turns and an angle valve, connecting to a header 8 inches diameter from the Stirling boiler No. 1 to No. 2, and 12 feet long, connected by an 8 x 12 x 8 inch T to a 12-inch header,

28 feet long, having two turns, to the main steam-pipe before spoken of in connection with the Babcock & Wilcox boilers.

During the main test the Stirling boiler No. 2 was piped directly to condenser engines, to feed-water and fuel-oil pumps, and to heating system for building, as follows: A 3-inch pipe, 96 feet long, with five turns to the feed pumps, pipe bare; a $3\frac{1}{2}$-inch pipe, 208 feet long, with five turns, runs to the condenser engines – 108 feet of this pipe in the basement was covered; a 3-inch steam-pipe to the heating system of the building.

FIG. 383.

All other steam-pipes are protected by, first, a dead air-space of $\frac{5}{8}$ inch, made by a sheet-iron cylinder with collars turned in at the ends, and then covered with asbestos cement $\frac{7}{8}$ inch thick.

The tri-cylinder engines are of the cross compound type with the high pressure, and intermediate cylinders arranged tandem on one side, and the low pressure by itself on the opposite side, with its crank 90° from the other, and reheater receivers between the cylinders.

The exhaust from the H P. cylinder is carried to No. 1 receiver, which is $27\frac{1}{2}$ inches diameter and 15 feet 6 inches long,

and from which the supply to the intermediate cylinder is taken.

The exhaust from the intermediate cylinder is carried to No. 2 receiver, which is $28\frac{1}{2}$ inches in diameter and 21 feet 6 inches long.

These receivers are surrounded by a jacket space of $1\frac{5}{8}$ inches, the whole protected by a covering of asbestos, except the ends, which are uncovered.

The cylinders of both engines have a steam-jacket space of

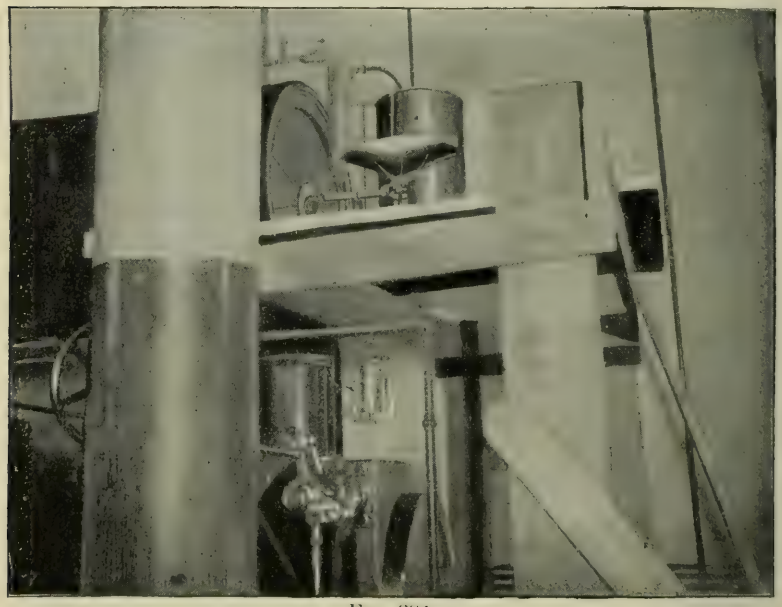


FIG. 384.

about $1\frac{1}{2}$ inches, and are then covered with a layer of asbestos cement $2\frac{1}{2}$ inches thick, covered over all with sheet-steel. The heads are jacketed, but not covered with asbestos. All ends except the crank-ends of the intermediate and low-pressure cylinders have false covers.

The steam for these jackets is taken from the main steam-pipe after leaving the separator No. 1; on the one side it passes around the H. P. cylinder, then around the intermediate cylinder, then around receiver No. 1. On the other side it passes first around the low-pressure cylinder, and then around the receiver No. 2, between the intermediate and low-pressure cylinders.

DIMENSIONS OF ENGINES.

Diameter of high-pressure cylinder	$24\frac{3}{4}$	inches
Diameter of intermediate cylinder	$40\frac{1}{16}$	inches
Stroke of intermediate piston	$59\frac{3}{32}$	inches
Diameter of low-pressure cylinder	$56\frac{7}{64}$	inches
Length of stroke, low-pressure piston	$59\frac{55}{64}$	inches
Clearance of high-pressure cylinder, by measurement	4.1%	
Clearance of intermediate-pressure cylinder, by measurement	5.3%	
Clearance of low-pressure cylinder, by measurement	4.2%	
Diameter of H. P. rod	$3\frac{5}{8}$	inches
Diameter of I. P. rod	$4\frac{5}{8}$	inches
Diameter of L. P. rod	$4\frac{5}{8}$	inches
Connecting rods: diameter at centre	7	inches
Connecting rods: diameter at ends	$5\frac{1}{2}$	inches
Connecting rods: length	15	feet
Crank-pin diameter	7	inches
Crank-pin length	8	inches
Main bearings	15	inches
Shaft at fly-wheel	17	inches
Fly-wheel diameter	28	feet
Fly-wheel face	73	inches
Steam-pipe to H. P. cylinder	8	inches

FIG. 385.

PIPING.

Exhaust pipe from H. P. cylinder....10 inches diameter, 14 feet long, 3 turns
Supply pipe to I. P. cylinder.....12 inches diameter, $16\frac{1}{2}$ feet long, 2 turns

Exhaust pipe from I. P. cylinder.....14 inches diameter, 2 feet long, 2 turns
Supply pipe to L. P. cylinder.....14 inches diameter, 15 feet long, 2 turns
Exhaust pipe from L. P. cylinder....16 inches diameter, 71½ inches long, 6 turns

CONDENSER ENGINES.

Diameter of steam cylinders.....11.98 inches
Diameter of air-pump cylinders.....28.00 inches
Stroke of pistons and plungers.....12.00 inches

SUMMARY OF RESULTS. TEST NO. 1.

Time of beginning test.....4.20 A.M., March 5, 1892
Time of closing test.....1.50 A.M., March 6, 1892
Duration of test.....21 hours 30 minutes
Engines in use.....Two tri-cylinder condensing Allis engines

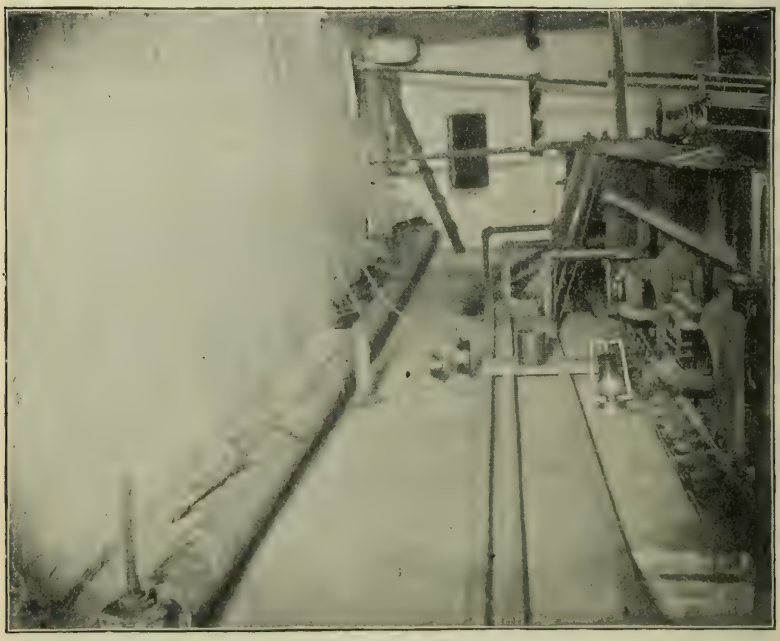


FIG. 386.

Boilers in use.....Nos. 1, 3, 4, 5, Babcock & Wilcox boilers
Total water as evaporated.....525,487 lbs.
Less 1½% average moisture.....517,601 lbs.
Water collected from separator No. 1.....5,778 lbs.
Water collected from separator No. 2.....1,896 lbs.
Water collected from both.....7,674 lbs.
Steam condensed in empty Stirling boiler No. 1 (leaky valve).....3,024 lbs.
Water collected from jackets.....47,129 lbs.
Total dry steam used in engines (not including jackets).....459,773 lbs.
Total oil used.....44,245 lbs.

Average temperature of feed water	123.4°
Average steam pressure in boiler room	122.4 lbs.
Average temperature of flue gases	385°
Average temperature of boiler room	82.5°
Average draught in flue	$\frac{3}{4}$ inch
Average height of barometer	28.77 inches
Average temperature of oil	101.7°
Average moisture in steam	$1\frac{1}{2}\%$
Average temperature of injection water (about)	38°
Average revolutions per minute, engine No. 1	62.26
Average revolutions per minute, engine No. 2	63 00
Average horse-power, engine No. 1	705.83
Average horse-power, engine No. 2	621.23
Maximum horse-power at any time, engine No. 1 (at 7.50 P.M.)	1,097.30
Maximum horse-power at any time, engine No. 2 (at 5.50 P.M.)	1,040.96
Maximum horse-power at any time, both engines (at 5.50 P.M.)	2,046.2
Average total horse-power during run, both engines	1,237.9
Average horse-power used for lighting purposes	33.4
Average total horse-power during run available for car use	1,204.5
Average horse-power used by condenser engines	13.66
Average electric horse-power	1,088.00
Ratio of horse-power of condenser engines to horse-power of main engines	$1\frac{1}{10}\%$
Ratio of total steam used in jackets to steam used in cylinders	$9\frac{15}{100}\%$
Loss by friction between engines and line, obtained by taking the difference between steam and electric horse-power	149.00
Loss by friction in %	$12\frac{3}{10}\%$

The power used by the condenser engines was practically constant under all variations of load on the main engines.

In calculating the ratio of steam used in jackets to that used in the cylinders of the main engines the water collected by the separators was deducted from the amount chargeable to the boilers, also the leakage from the leaky valve before noted.

Average water used in Stirling boiler for condenser engines, pumps, and heating system, per hour	5,837.6 lbs.
Average water used in main engines, without jackets, per hour	21,385.0 lbs.
Steam used in cylinders per horse-power per hour, as evaporated	17.29 lbs.
Steam used in cylinders per horse-power per hour, from and at 212°	19.54 lbs.
Steam used in cylinders and jackets per horse-power per hour, as evaporated	19.05 lbs.
Steam used in cylinders and jackets per horse-power per hour, from and at 212°	21.52 lbs.
Evaporation of water per pound of oil, as used	11.87 lbs.
Evaporation of water per pound of oil, from and at 212°	13.50 lbs.
The oil analyses show a possible evaporation of water, from and at 212°, of	20.64 lbs.

NOTE.—The steam consumption here given includes that used for atomizing the fuel oil in the B. & W. boilers.

Taking 20.64 lbs. as the evaporative power of the oil and 15 lbs. as that of standard coal, the above evaporation is equivalent to 9.79 lbs. of water per pound of coal, from and at 212°.

Standard oil is considered to have an evaporative power, from and at 212°, of 22.00 lbs.

COST PER HORSE-POWER.

Cost of fuel oil for main engines, using steam of 1½% saturation, with fuel oil costing $0.0226 per gal., weighing 6⅜ lbs. per gal.; per day	$157.85
Cost of fuel oil for main engines, if using dry steam, and with condensation in main steam-pipe deducted	154.06
Cost of fuel oil for condensers, pumps and heaters	39.05
Cost of labor per day, exclusive of chief engineer and electrician	51.50
Cost of lubricating oil and waste (figures from office)	14.71
Total cost per day, exclusive of any water purchased	$263.11
Cost per hour of run	12.24
Cost per total horse-power per hour	0.0099
Cost per horse-power per hour on the line	0.01125

COST OF POWER PER CAR MILE, PER CAR HOUR, AND PER PASSENGER, MINNEAPOLIS, MARCH 5, 1892.

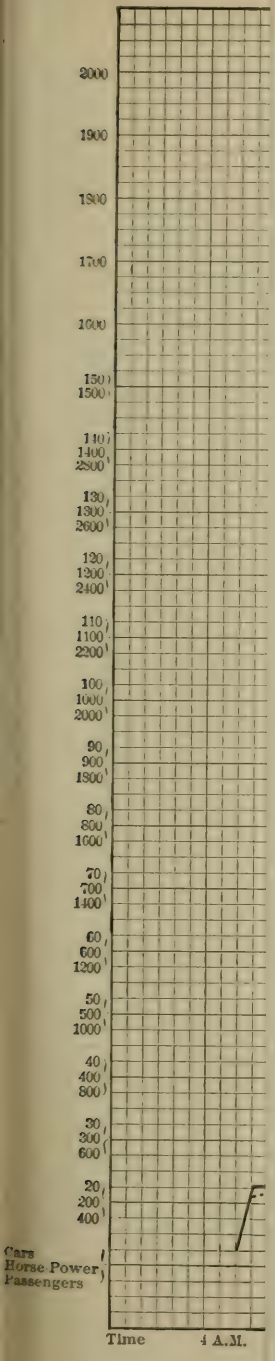
Total cost per day	$263.11
Total mileage (from Auditor's office)	17,451
Cost per car mile	$0.0151
Total car hours	2,435.16
Cost per car hour	$0.108
Total number of passengers (Auditor)	66,990
Cost per passenger	$0.00392

In comparing these figures with those obtained in the other tests, it should be remembered that the cost of heating the building and fuel oil is herein included.

Test No. 2—St. Paul, March 23, 1892.

The plant at St. Paul consists of three tri-cylinder cross-connected engines of similar design to those used in "Test No. 1," but with 48 inches stroke of pistons, and six Babcock & Wilcox boilers; two boilers, however, supplying the steam to the main engines exclusively, of similar dimensions to those used in "Test No. 1," and in all but a few cases, specially referred to, the conditions were the same as in "Test No. 1."

From the fly-wheel pulley on each of the engines two belts 40 inches wide run over 40-inch by 40-inch tightener pulleys, on the slack side of the belt, to pulleys 48 inches diameter by 40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Cars
Horse Power
Passengers
Time
4 A.M.

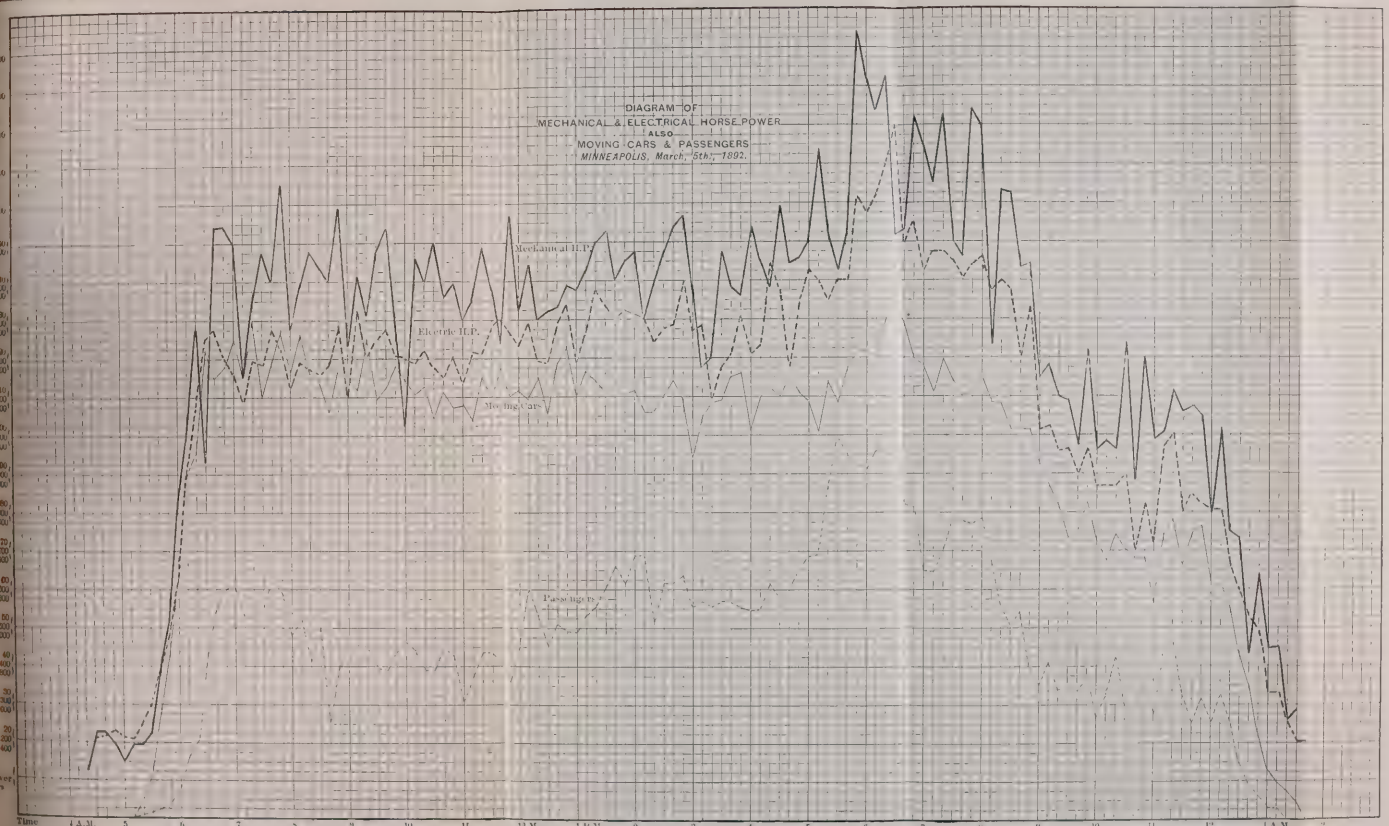


DIAGRAM OF
MECHANICAL & ELECTRICAL HORSE POWER
ALSO
MOVING CARS & PASSENGERS
MINNEAPOLIS, March, 5th, 1892.
Mechanical H.P.
Electric H.P.
Moving Cars
Passengers
Time
1 A.M.
12 M.
1 P.M.
1 A.M.

Fig. 397.

80
70
60
50
40

Fig. 388.

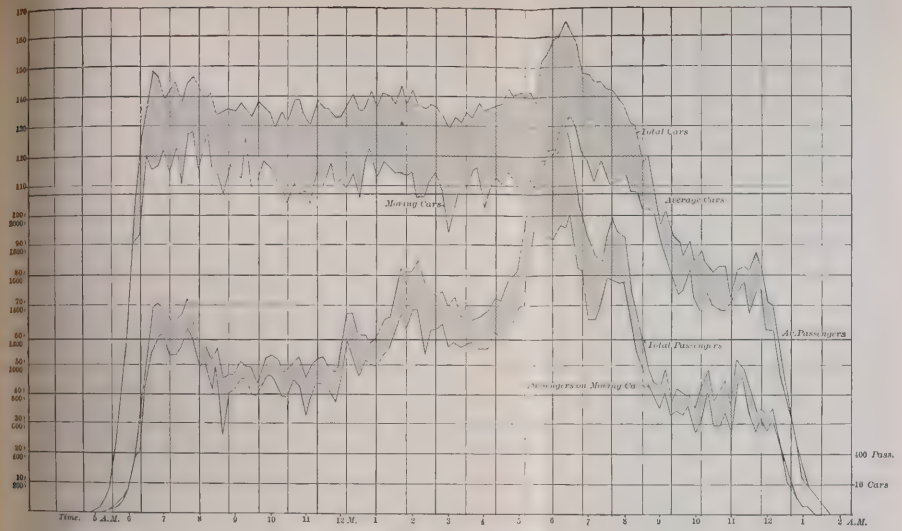


DIAGRAM OF CARS AND PASSENGERS
MINNEAPOLIS, MINN.
MARCH 5, 1892.

Fig. 389.

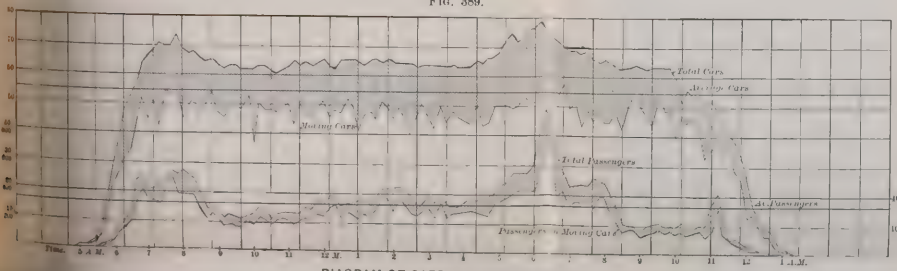


DIAGRAM OF CARS AND PASSENGERS
ST. PAUL, MINN.
MARCH 23, '92.

inches face. These pulleys are on 6-inch shafts, making 540 revolutions per minute. Driven by each 48-inch by 40-inch pulley is a generator attached to the pulley shaft by two 6-arm clutches, by which they can be disconnected at will.

Pantographs were used, instead of the pendulum motion of "Test. No. 1."

No separators were used, and the steam piping was all overhead.

SUMMARY OF RESULTS—TEST NO. 2, ST. PAUL.

Time of beginning test	4.40 A.M., March 23, 1892
Time of closing test	2.00 A.M., March 24, 1892
Duration of test	21 hours 20 minutes
Engines in use	Two tri-cylinder condensing Allis engines
Boilers in use	Nos. 1 & 2, Babcock & Wilcox
Total water evaporated	315,755 lbs.
Less 2 4/10 %, average moisture	308,177 lbs.
Less 1,748 lbs., collected from header	306,429 lbs.
Water collected from jackets	40,909 lbs.
Total dry steam used in engines (not including jackets)	265,520 lbs.
Total oil used	25,850 lbs.
Average temperature of feed water	155°
Average steam-pressure in boiler room	123 lbs.
Average temperature of flue gases	342°
Average temperature of boiler room	77°
Average draught in flue	5/8 inch
Average height of barometer	28.64 inches
Average temperature of oil	66°
Average moisture in steam	2 4/10 %
Average temperature of injection water	41.3°
Average revolutions per minute, engine No. 2	69.8
Average revolutions per minute, engine No. 3	69.4
Average horse-power, engine No. 2	418.47
Average horse-power, engine No. 3	427.53
Maximum horse-power at any time, engine No. 2 (6.20 P.M.)	822.3
Maximum horse-power at any time, engine No. 3 (8.00 P.M.)	807.0
Maximum horse-power at any time, both engines.	
Average total horse-power during run available for car use	756.2
Average total horse-power used by condenser engines	11.51
Average total electric horse-power	624.7
Ratio of horse-power of condenser engines to horse power of main engines	1 52/100 %
Ratio of total steam used in jackets to steam used in cylinders	13 4/10 %
Loss by friction between engines and line, obtained by taking difference between steam and electric horse-power	131.5 H.P.
Loss by friction, in %	17 4/10 %

It is believed that the loss in friction here given, as obtained by difference between mechanical and electrical horse-power, is

too low, as it will be seen, by reference to the diagram, that during the early morning and late at night, when the engines are running light, the difference between the two is very small, and even occasionally minus. This, it seems to the writers, is due to the imperfect regulation of the engines, it appearing to be a fact that the steam required under these circumstances is admitted in occasional puffs, as the governor occasionally opens the admission valve too wide, then remaining nearly closed for a much longer period. In this way, the cards obtained would be likely, as a general thing, to indicate less power than the engines are really exerting, and hence the friction loss would generally appear less than it really is.

Several sets of friction cards have been taken from these engines since the test, giving a loss of about 137 H.P. to each engine, and the line shaft and generators run by it. This would give as an average loss by friction for the whole run 258 H.P., or a little over 20%, which amount will be used later in comparing these engines with those at the Thirty-first Street Station, Minneapolis.

Average water used in auxiliary boiler for condensers, pumps and atomizers, per hour, as evaporated	2,673.1 lbs.
Average water used in main engines, as evaporated, per hour, without jackets	12,447. lbs.
Steam used in cylinders, per horse-power per hour, as evaporated	16.46 lbs.
Steam used in cylinders, per horse-power per hour, from and at 212°	18.15 lbs.
Steam used in cylinders and jackets, per horse-power per hour, as evaporated	19.00 lbs.
Steam used in cylinders and jackets, per horse-power per hour, from and at 212°	20.95 lbs.
Evaporation of water per lb. of oil, as used	11.54 lbs.
Evaporation of water per lb. of oil, from and at 212°	12.73 lbs.

COST PER HORSE-POWER.

Cost of fuel oil for main engines, using steam of $2\frac{4}{10}$% saturation, with fuel oil costing $0.0226 per gallon, and weighing $6\frac{3}{10}$ lbs. per gallon, per day	$92.21
Cost of fuel oil for main engines, if using dry steam	90.00
Cost of fuel oil for condensers, pumps and atomizers	19.39
Cost of labor, exclusive of chief engineer and electrician	23.83
Cost of lubricating oil and waste (figures from office)	7.82
Total cost per day, exclusive of any water purchased	143.25
Cost per hour of run	6.71
Cost per total horse-power per hour	0.00887
Cost per horse-power on the line, per hour	0.01074

COST OF POWER PER CAR MILE, PER CAR HOUR, AND PER PASSENGER—ST. PAUL, MARCH 23, 1892.

Total cost per day	$143.25
Total mileage (from Auditor's office)	9,848.
Cost per mile	$0.01443
Total car hours	99,055.
Cost per car hour	$0.1446
Total number of passengers (Auditor)	28,825.
Cost per passenger	$0.004969

Test No. 2*b*, St. Paul Power House, May 12, 1892.

Object of Test.

This test was made to ascertain the steam consumption of the condenser engines used in tests No. 1 and No. 2. The steam from one Babcock & Wilcox boiler supplied the two condensing engines exclusively, and the water was weighed, as usual in these tests.

Duration of test, in hours	7.11
Total water used, as evaporated	7,859.00 lbs.
Moisture in steam	$2\frac{8}{10}\%$
Total dry steam, as evaporated	7,640.00 lbs.
Dry steam per hour, as evaporated	1,074.5 lbs.
Average total horse-power	14.03
Average temperature of feed water	160°
Average pressure of steam	127.4 lbs.
Dry steam per horse-power per hour, as evaporated	76.58 lbs.
Dry steam per horse-power per hour, from and at 212°	88.14 lbs.

Test No. 2*c*, Using Coal—St. Paul, Minn., March 28, 1892.

Average moisture in steam	4.8%
Total coal	35,750 lbs.
Total ash	2,451 lbs.
Coal burned	33,299 lbs.
Feed water	224,564 lbs.
Average temperature of feed water	82.15°
Average steam-pressure	121.5 lbs.
Feed water, less 4.8%	213,785.
Feed water, from and at 212°	250,769.8
Water per pound coal evaporated	6.4
Water per pound coal, from and at 212°	7.5
Extra cost over oil for labor per day, burning coal	$8.37
Extra cost during thirteen hours' run	$5.10
Cost of labor, lubricating oil, and waste as usual for thirteen hours' run	$19.29

Total cost of labor, lubricating oil, and waste, burning coal thirteen hours	$24.39	
Cost of coal at $4.85 per ton	86.69	
Add proportion of coal for condenser engines, pumps, and atomizers as evaporated	18.69	
		$129.77
Cost to evaporate 1 lb. water		0.000423
Cost per indicated horse-power per hour		0.010659
Cost per average horse-power on line		0.01294
Ratio of cost of power burning coal to cost burning oil, 120 : 100; or coal costs more than oil		20%

RELATIVE COST OF POWER BURNING OIL AT $0.0226 PER GALLON AND BURNING COAL AT PRICES VARYING FROM $2.00 TO $4.85 PER TON, ASSUMING AN EVAPORATION FROM THE COAL OF 7½ LBS. WATER FROM AND AT 212°.

COAL AT $2.00 PER TON.

Cost per horse-power per hour	$0.005631
Saving over oil	$37\frac{1}{10}$%

COAL AT $2.25 PER TON.

Cost per horse-power per hour	$0.006099
Saving over oil	$31\frac{3}{10}$%

COAL AT $2.50 PER TON.

Cost per horse-power per hour	$0.00655
Saving over oil	$26\frac{9}{10}$%

COAL AT $3.00 PER TON.

Cost per horse-power per hour	$0.007452
Saving over oil	$16\frac{7}{10}$%

COAL AT $3.50 PER TON.

Cost per horse-power per hour	$0.008354
Saving over oil	$6\frac{8}{10}$%

COAL AT $4.00 PER TON.

Cost per horse-power per hour	$0.009256
Cost above oil	$3\frac{4}{10}$%

COAL AT $4.50 PER TON.

Cost per horse-power per hour	$0.010158
Cost above oil	$13\frac{4}{10}$%

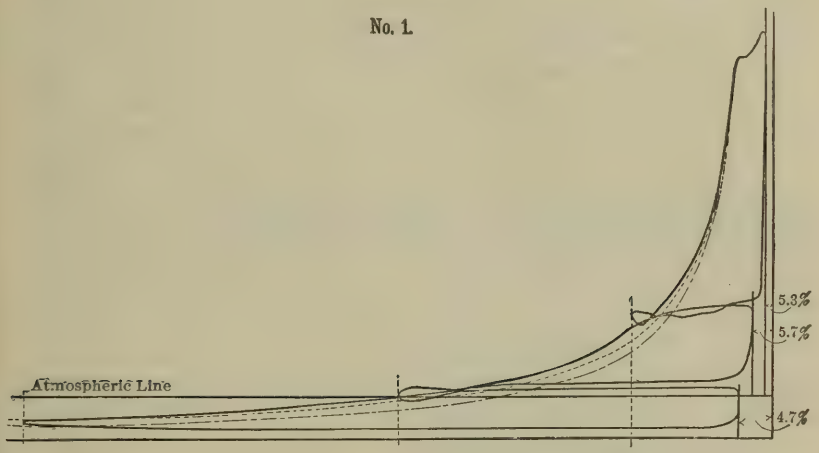
COAL AT $4.85 PER TON.

Cost per horse-power per hour	$0.01069
Cost above oil	$19\frac{0}{10}$%

From these figures the relative economy of any coal, the evaporating power of which is known, can be computed.

For example, a coal which has an evaporating power of only $\frac{4}{5}$ of that stated, would be equivalent to coal at $\frac{5}{4}$ the price.

FIG. 390.



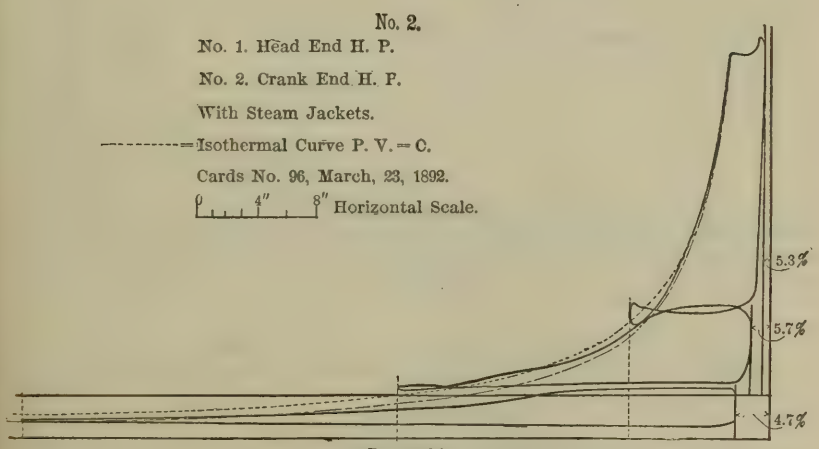
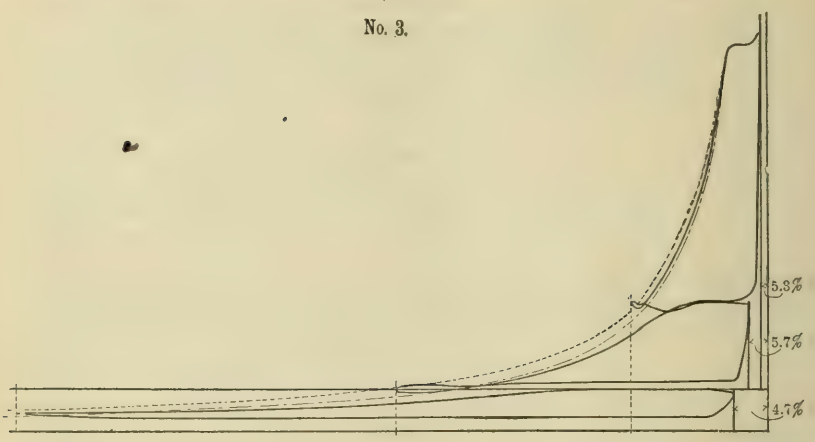


FIG. 391.

Thus, if coal that can be bought for \$2.00 per ton requires $1\frac{1}{4}$ tons to evaporate as much as one (1) ton of Youghiogheny, it is equivalent to coal costing \$2.50 per ton, or the saving over oil would be $26\frac{2}{10}\%$.

FIG. 392.



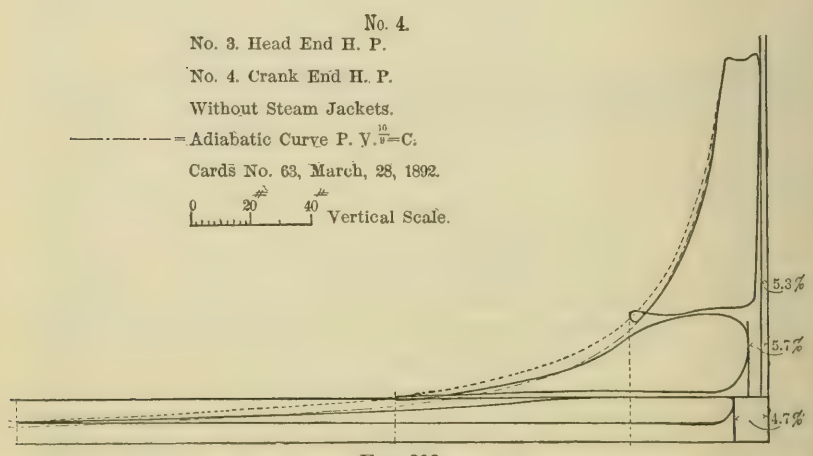


FIG. 393.

TEST NO. 2*d*, ST. PAUL POWER HOUSE, JULY 23, 1892.

Object of the Test.

This test was made to ascertain the relative value of hard coal screenings (with about $2\frac{8}{10}\%$ of bituminous screenings) at \$1.40 per ton, and oil at \$0.0258 and \$0.0261 per gallon; and to obtain the efficiency of the engine, when one engine was doing all the work, more generators having been added to each engine.

DURATION OF THE TEST.

The test began at 9.15 A.M. and closed at 7.15 P.M., a period of ten hours.

The boilers were in good condition, and the fires left at the close in the same condition as at starting. Besides the observations taken in the boiler room, indicator diagrams were taken on the tri-cylinder condensing engine No. 3, which was furnishing power to the road; also ammeter readings to obtain the useful or electric horse-power.

SUMMARY OF RESULTS.

Total water furnished boilers	201,923 lbs.
Percentage of moisture	$2\frac{6.6}{100}$
Net water evaporated	196,532 lbs.
Average steam-pressure	127 lbs.
Average temperature of feed water	178.4°
Equivalent water from and at 212°	212,154 lbs.
Total coal consumed	34,318 lbs.
Water as evaporated per pound coal	5.72 lbs.
Equivalent water from and at 212°	6.18 lbs.

INDICATOR RECORDS TAKEN FROM 10 A.M. TO 5.20 P.M.

Average horse-power for whole period	859.73
Total water for this period, less $2\frac{6.6}{100}\%$ moisture	138,695 lbs.
Water per hour	18,912 lbs.
Water as evaporated per horse-power per hour	21.99 lbs.
Water from and at 212° per horse-power per hour	23.74 lbs.

PERIOD FROM 3.20 TO 5.20.

Average horse-power	892.36
Total water evaporated	35,472 lbs.
Water as evaporated per horse-power per hour	20.42 lbs.
Water from and at 212° per horse-power per hour	22.05 lbs.

AVERAGE ELECTRICAL HORSE-POWER.

From 10 A.M. to 5.20 P.M.	737.35
From 3.20 to 5.20 P.M.	812.20

HORSE-POWER USED IN FRICTION: OBTAINED BY TAKING THREE (3) SETS OF CARDS FOR EACH CASE.

No load on generators	164.43
Generators dead	137.51
Clutches thrown off	150.96
Per cent. of friction to total horse-power, 164.43 : 859.73	19.12%

It will be noticed in this connection that more horse-power is required after the "clutches are thrown off," than when the "generators are dead;" that is, when the switch on the generator is thrown, and no electricity is being generated. This feature has been observed so often that unless it be due to some effect of the magnetism of the fields, the inertia of the moving parts will possibly be responsible.

EXTRA HELP REQUIRED TO HANDLE COAL.

Four firemen at $2.00 per day, per month	$240.00
Two coal-handlers at $55.00 per month	110.00
Extra per day	11.66
Extra per hour, 21½ hours per day	0.55

COST PER HORSE-POWER PER HOUR.

34,318 lbs. coal, as above, at $1.40 per ton.....per day	$24.02
Cost per hour for coal	2.40
Cost per hour for labor, as usual	1.12
Extra for labor, as above	.55
Waste and lubricating oil per hour	.36
Total cost per hour	$4.43
Cost per horse-power per hour	$0.00515
Cost per horse-power per hour, burning oil at $0.0261 per gallon, from Test No. 2	.009952
Saving over oil as above, when burning screenings	48 3/10%
Cost per horse-power per hour burning oil at $0.0258 per gallon	$.00986
Saving	47 8/10

EFFECT ON EFFICIENCY OF RUNNING ENGINE NEARER ITS RATING THAN IN TEST NO. 2.

Total water per horse-power per hour, including condensers, atomizers, etc., as above	23.74 lbs.
Total water for same, from Test No. 2	25.43 lbs.
Saving due to proper loading	6 7/10%

TEST NO. 2*c*—EFFECT OF STEAM-JACKETS ON STEAM CONSUMPTION.

On the 28th of March a run of 13 hours was made without steam in the jackets, and the total water consumed was 211,461 lbs., or an equivalent of 232,812 lbs. from and at 212°.

The average horse-power for the 13 hours was 1,018.6, giving consumption of water, as evaporated, 16.00 lbs. per horse-power per hour, or an equivalent of 17.62 lbs. from and at 212°, as compared with a consumption of 20.95 lbs. per horse-power per

hour from and at 212°, with steam-jackets in operation, and the steam used therein charged up to the engine.

This shows that under those conditions the engines were

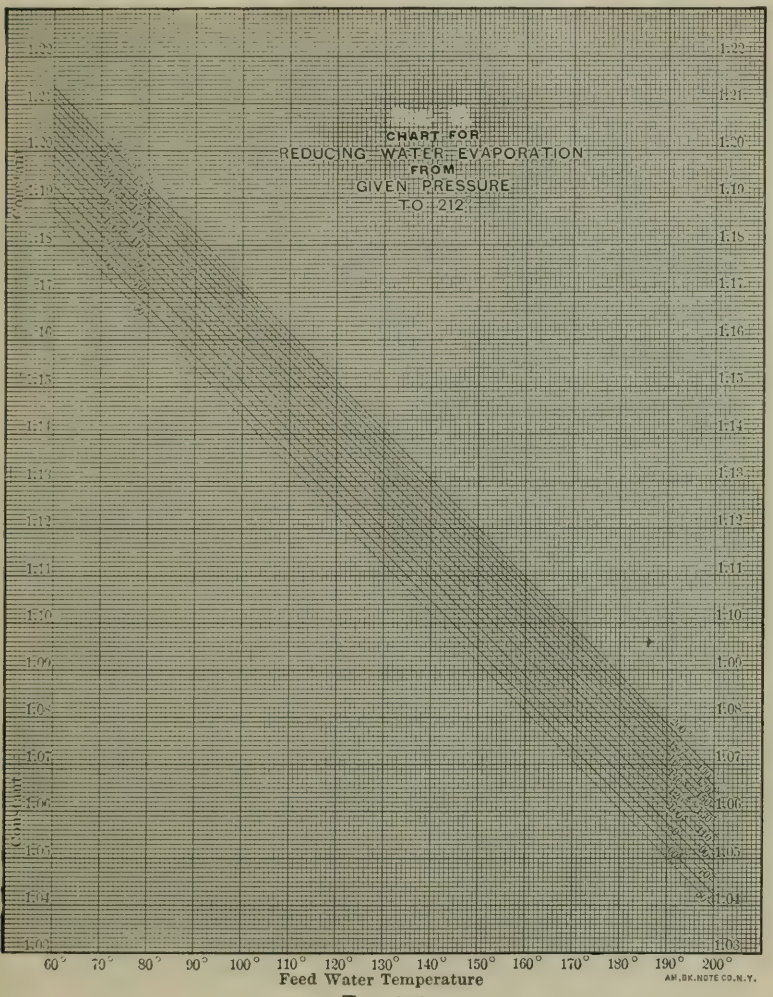


FIG. 394.

more efficient by 15.54% without the jackets, and this accords with the observations of the engineers of the plant.

The only objection to these results is the fact that this test did not include the parts of a full day's run when the power was least, and therefore when the engines were least efficient. It is not believed, however, that this would overcome the difference

stated above, and the conclusion is forced upon us that under the conditions as then existing the jackets are of no value.

The water of condensation from the steam-jackets was, at the Minneapolis plant, collected in barrels with one platform scale for each jacket, as it was considered possible by having two barrels to handle the water, and it was so done, but entailed considerable manual labor.

Profiting by this experience, a different plan was adopted at St. Paul, which worked perfectly. Two platform scales, each with a barrel on it, were provided for each jacket trap and so arranged that each could be filled separately; and after being weighed, the water was drawn off into a drain under the scales through a pipe and valve inserted in the bottom of the barrel, and while being emptied the other barrel was being filled. The time when each barrel began to receive water, when emptied, and the weight, was noted for each jacket.

With a tight cover on the barrels it was not thought necessary to use cold water to cool the jacket water, and it is not thought that the moisture contained in the slight amount of escaping steam would materially alter the result. Still, when it can be done, it will be found still more satisfactory to cool the water of condensation while being weighed.

Test No. 3—Thirty-first Street Station; Minneapolis, October 21 and 26, 1892.

The plant at Thirty-first Street consists of ten (10) 16 inches by 27 inches by 16 inches Westinghouse compound engines, nine of which are belted directly to Thomson-Houston generators; the other is belted to an exciter and to an arc-light machine.

Five of the engines only were in service at the time of the test, and were connected to the main steam-drum in the boiler-room by long 8-inch pipes with a number of ells and valves in each.

There are seven (7) Stirling boilers of 287 nominal horse-power each. These are connected by 8-inch pipes to the main steam-drum above referred to.

During the first test, boiler No. 7 was disconnected from the steam-drum and used for furnishing steam for pumps, atomizers, etc., and enough of the other boilers were used to furnish steam to the engines.

During the variable load or service test, boiler No. 7 was not

used, and the other boilers in service furnished all steam used for engines, pumps, and atomizers; all connections to boilers except those in use were blanked off or known to be tight.

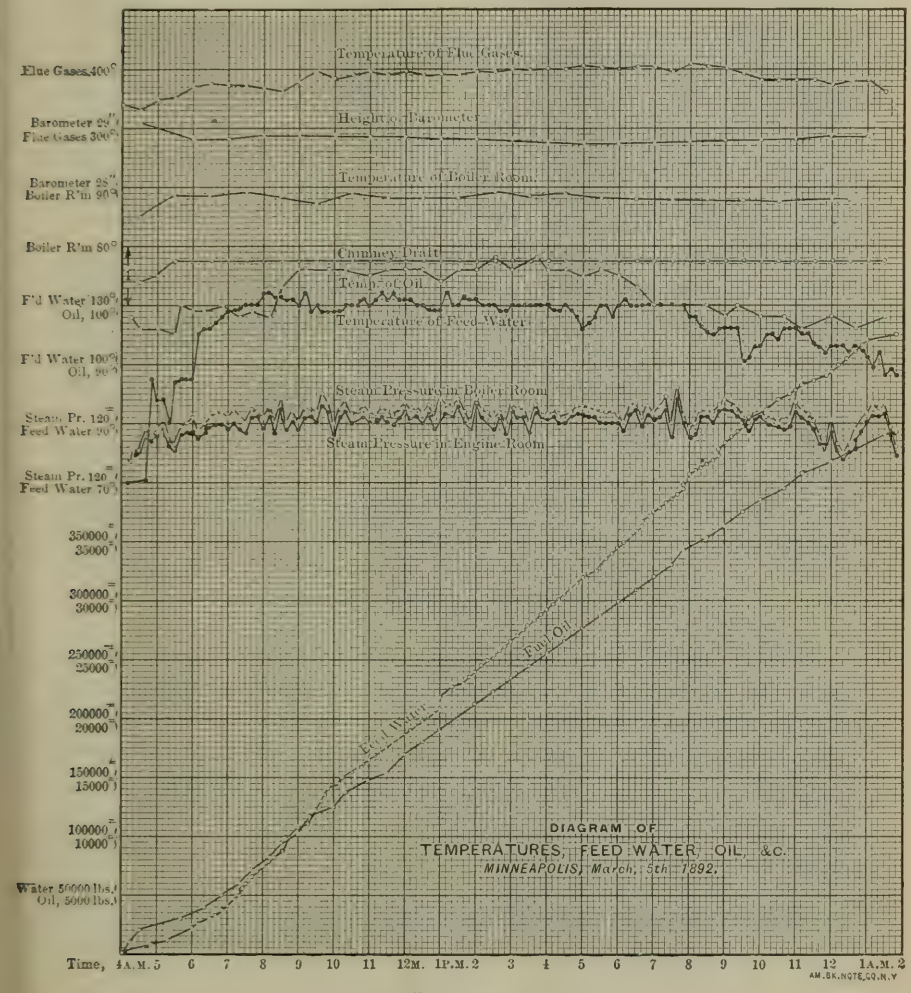


FIG. 395.

The same apparatus for weighing water, oil, etc., and for determining other data, was used as in the tests of the other plants, except that iron tanks were used for weighing the water and the same precautions taken to insure that the results would be reliable.

RHEOSTAT FOR OBTAINING A STEADY LOAD.

In order to obtain a steady load on these engines, it was first proposed to pass the current through a water rheostat composed of wrought-iron rods $\frac{1}{4}$ inch in diameter, in a tank through which water was kept circulating. It was found, however, that after a short time scale, similar to that deposited in boilers, would collect on the rods and that then they would burn out. To obviate this difficulty, an open-air rheostat was extemporized by Messrs. Cooper & Morell, of the Street Railway Co. This rheostat consisted of 1,200 feet of $\frac{1}{2}$-inch iron rods, clamped together and arranged in two sets of 600 feet each in parallel. This combination was supported on bearers placed across a repair-pit in the car house. By this means it was found practicable to obtain a very steady load of any amount required, the only trouble being that in some cases the joints were imperfect, due to the haste in which the rods were put together.

Later tests, with a more carefully constructed rheostat, have given entire satisfaction. In this way a steady load can be obtained much more easily than by means of a friction or Prony brake, wherever engines are used for running generators.

Steady Load Test, October 21, 1892.

It was intended to make a continuous run of eight or ten hours under a steady load, obtained by passing the current from the generators through the water rheostat above referred to. On account, however, of scale forming on the wires the rheostat burned out after a short time, and it became necessary to improvise a new rheostat, as also referred to above. This mishap reduced materially the length of the test under steady load, but the records were so carefully taken that each ten minutes gave results complete in themselves, so that the final results, as given below, are considered to be as accurate as if the actual running-time were longer.

SUMMARY OF RESULTS.

Duration of test	4 h. 25 m.
Average horse-power	783.3 H.P.
Average steam-pressure at boilers	131.5 lbs.
Average steam-pressure at engines	118.5 lbs.
Average moisture in steam	4%
Total water per hour, as evaporated	19,549.5 lbs.

Net dry steam per hour, as evaporated	18,798. lbs.
Average steam per horse-power per hour under above conditions	23.51 lbs.
Probable average steam per hour, if full boiler-pressure had been had at engines (loss estimated at 4%)	22.47 lbs.
Average temperature of feed water	57.44°
Total water furnished main boilers	83,083 lbs.
Amount of water collected from drips and loop	1,760 lbs.
Net dry steam from main boilers	79,759.7 lbs.
Total water furnished for pumps, atomizers, etc	14,540 lbs.
Percentage of steam required for pumps, atomizing oil, etc., as compared with steam used in engines, reduced to same pressure	15.9%

Test No. 3—A Test to Determine Cost of Atomizing Oil.

To settle this question, a run of three and one-half ($3\frac{1}{2}$) hours was made October 24, 1892, during which the auxiliary boiler was used to furnish steam for atomizing the fuel oil only, and the amount of steam used for this purpose and also the amount evaporated for the use of the engines determined.

RESULTS.

Total water from boilers used for service	53,734 lbs.
Total water from boilers used only for atomizing oil	8,330.5 lbs.
Average steam-pressure in service boilers	132.7 lbs.
Average steam-pressure in atomizer boiler	131.8 lbs.
Ratio of water used for atomizing to total water for all purposes	13.4%

Test No. 3*b*—Test of Plant in Actual Service, October 26, 1892—Length of Test, 20 Hours 40 Minutes.

Total water used in boilers	354,705.4 lbs.
Moisture in steam	4.05%
Total dry steam	330,517.2 lbs.
Average pressure in boilers	134.4°
Average temperature of feed water	54.4°
Average horse-power	522.5
Maximum horse-power	901.25
Minimum horse-power	77.49
Average dry steam per horse-power per hour	29.2
Average electric horse-power	434.2
Average loss in horse-power between engines and line (by difference)	88.3
Percentage of loss between engines and line	16.9%
Friction of engine alone in horse-power as determined by friction cards	14.27 H.P.
Percentage as compared with maximum horse-power of any one engine	$3\frac{7}{10}$%
Equivalent water, from and at 212°, per pound fuel oil	14.48 lbs.
Equivalent evaporation per pound standard coal	9.87 lbs.
Cost of fuel oil for whole test	$99.07

Total car mileage	6,296.4
Cost for fuel oil per car mile	$.01573

SUMMARY OF RESULTS, ALL TESTS—COMPARATIVE COST PER HORSE-POWER PER HOUR.

From tests made at the Thirty-first Street Station, under the title of "Test No. 3," it is determined that the cost of running the necessary pumps and atomizing the fuel oil is, in percentage of the whole power	$15\frac{3}{10}\%$
Cost, in percentage of the whole power, of atomizers	$13\frac{4}{10}\%$
Cost, in percentage of the whole power, of pumps	$2\frac{5}{10}\%$
Cost of fuel oil for main engines, "Test No. 1," using steam of $1\frac{1}{2}\%$ saturation, with fuel oil costing $0.0226 per gallon, weighing $6\frac{3}{10}$ lbs. per gallon, per day, including atomizers	$157.85
Cost of running necessary pumps	3.95
Cost of running condenser engines	6.87
Total cost of power, "Test No. 1," per day	$168.67
Cost of labor, per day	51.50
Cost of lubricating oil and waste, per day	14.71
Total cost per day	$234.88
Cost, as above, per hour	10.92
Cost, as above, per horse-power per hour	$0.00881
Cost, as above, per electric horse-power per hour	0.01004
Cost, as above, per car mile	0.01346
Cost of fuel oil for main engines, "Test No. 2," using steam of $2\frac{4}{10}\%$ saturation, with fuel oil costing $0.0226 per gal., weighing $6\frac{3}{10}$ lbs. per gal.; per day, not including atomizers	$92.21
Cost of steam for atomizers	12.35
Cost of running necessary pumps	2.30
Cost of running necessary condenser engines	5.75
Total cost of power, "Test No. 2"	$112.61
Cost of labor per day	23.83
Cost of lubricating oil and waste, per day	7.82
Total cost per day	$144.26
Cost, as above, per hour	$6.76
Cost, as above, per horse-power per hour	0.00895
Cost, as above, per electric horse-power per hour	0.01083
Cost, as above, per car mile	0.01464

NOTE.—The slight difference between the cost per horse-power given here, and that from the other test, comes from assuming the cost of atomizing oil, running pumps, condenser engines, etc.—as given by percentages. The results are within less than one per cent. of each other, showing the cost of atomizing, etc.—as obtained directly and by the above percentages—to agree remarkably well.

Cost of fuel oil for main engines, "Test No. 3," using steam of $4\frac{5}{100}\%$ saturation, with fuel oil costing $0.0226 per gal., weighing $6\frac{3}{10}$ lbs. per gal.; per day, including steam used for atomizers, and necessary pumps	$99.04
Cost of labor per day	16.83
Cost of lubricating oil and waste, per day	4.02
Total cost per day	$119.89
Cost, as above, per hour	$5.80
Cost, as above, per horse-power per hour	0.01110
Cost, as above, per electric horse-power per hour	0.01336
Cost, as above, per car mile	0.01904

It must be noted here that in comparing the cost of power during "Test No. 3" with that of "Test No. 1" and "Test No. 2," less than half of the power of the plant was used from which the data was obtained for "Test No. 3," and, consequently, the item of labor is somewhat high in proportion to the horse-power developed, for with double the horse-power the labor item would not be materially increased.

COMPARISON OF COST PER CAR MILE—SUBDIVIDED POWER *vs.* CONCENTRATED POWER.

In making this comparison, the results as obtained from above tests at Thirty-first Street are compared with those obtained from the test of the triple expansion engines at Power House No. 1.

In order that the results may be properly compared, the following assumptions are supposed to apply to both plants, though they were different when the tests were made.

Cost of fuel oil per gallon	$.0257
Evaporation, from and at 212°, per pound of oil	14.48 lbs.
Total car mileage to be provided for	17,118
Average horse-power for 21 h. 30 m. for above mileage, Power House No. 1	1,203.5
Average horse-power for 21 h. 30 m. for above mileage, Thirty-first Street Power House	1,173.0

NOTE.—This difference comes from the difference in friction at the two stations. At No. 1 it is estimated at 20%, and at Thirty-first Street at 17%.

The following figures, which are as close as could be obtained from the auditor's office, are the basis of the "fixed charges" which go to make up total cost, and will serve as basis of comparison.

Value of real estate and buildings, assumed to be the same for both plants for comparison	$35,000.00
Value of engines, Power House No. 1	60,000.00
Value of boilers, Power House No. 1	25,000.00
Value of line shafting, Power House No. 1	15,500.00
Value of belting, Power House No. 1	5,000.00
Total	$105,500.00
Value of engines at Thirty-first Street	$35,000.00
Value of boilers at Thirty-first Street	25,000.00
Value of belting at Thirty-first Street	1,500.00
Total	$61,500.00
Rate of interest on investment	6%
Rate of depreciation on machinery, boilers, etc	10%

COST OF LABOR, POWER HOUSE NO. 1.

10 men at $55.00 per month	$550.00
4 men at $65.00 per month	260.00
1 man at $75.00 per month	75.00
1 man at $80.00 per month	80.00
1 man at $100.00 per month	100.00
Total	$1,065.00

Or $35.50 per day.

COST OF LABOR, THIRTY-FIRST STREET.

6 men at $55.00	$330.00
1 man at $75.00	75.00
1 man at $100.00	100.00
Total	$505.00

Or $16.83 per day.

Cost of superintendence reckoned at $2.75 per day per station.

COST OF LUBRICATING OIL AND WASTE, POWER-HOUSE NO. 1.

Cylinder oil, 126 gallons per month, at 50 cents	$63.00
Engine oil, 94½ gallons per month, at 25 cents	23.62
500 lbs. waste at 10 cents	50.00
Total	$136.62

Or $4.55 per day.

COST OF LUBRICATING OIL AND WASTE AT THIRTY-FIRST STREET, IF ALL ENGINES WERE IN USE.

Cylinder oil, 63 gallons	$31.50
Engine oil, 60 gallons	12.00
Crank-case oil, 378 gallons	56.70
Waste, 200 lbs	20.00
Total	$120.20

Or $4.00 per day.

/ER

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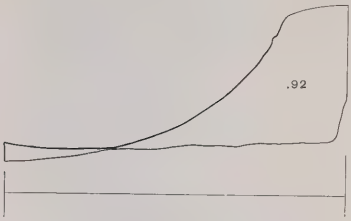
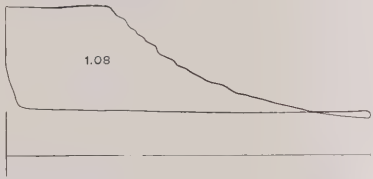
Fig. 396.

No. 89, Minneapolis, March 5, 1892.



Crank End. H. P. No. 2. 80 S.



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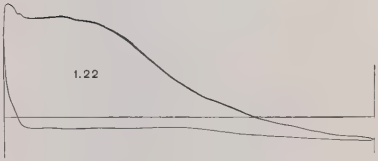

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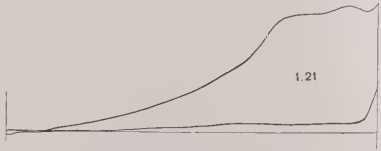

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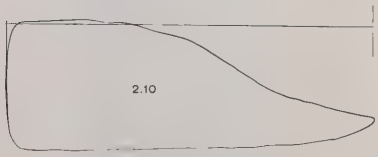

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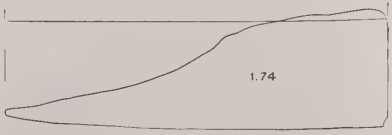


Crank End. L. P. No. 2. 16 S.

TOTAL COST PER DAY OF 21 HOURS 30 MINUTES, AT POWER HOUSE NO. 1—CAR MILEAGE, 17,118.

Fuel oil for 1,203 H.P. at rate of 25.4 lbs. water per horse-power per hour from and at 212°, and 14.48 lbs. water from and at 212° per lb. oil	7,258. gals.
Cost at $0.0257 per gallon	$186.53
Interest on machinery	17.58
Interest on real estate and buildings	5.59
Depreciation of machinery	29.30
Lubricating oil and waste	4.55
Labor	35.50
Superintendence	2.75
Cost per car mile, Power House No. 1, for fuel oil, labor, lubricating oil, waste, and superintendence	$.013333
Cost per car mile for interest and depreciation	.003065

Total Cost per Car Mile, Power House No. 1, $0.16398.

NOTE.—This includes, as it should, 4.5 lbs. per horse-power per hour for condenser engines, pumps, atomizing oil, etc.

TOTAL COST PER DAY OF 21 HOURS 30 MINUTES, AT THIRTY-FIRST STREET STATION, IF CAR MILEAGE WERE 17,118.

Fuel oil for 1,173 H.P., at rate of 33.28 lbs. water per horse-power per hour	9,200 gals.
Cost at $0.0257 per gallon	$236.55
Interest on machinery	10.11
Interest on real estate	5.59
Depreciation of machinery	16.88
Lubricating oil and waste	4.02
Labor	16.83
Superintendence	2.75
Cost per car mile, Thirty-first Street Station, for fuel oil, labor, lubricating oil and waste, and superintendence	$0.01513
Cost per car mile for interest and depreciation	0.00190
Total cost per car mile, Thirty-first Street	0.01703
Percentage in favor of concentrated power	$3\frac{2}{10}\%$

In this comparison of concentrated and subdivided power it has been our object to put both plants on the same basis as far as it is proper, and to make the result depend on the real difference between the two. For these reasons the Thirty-first Street plant has been treated as if it were covering the same mileage as the No. 1 plant, and that it required the same horse-power, on the line, to do it.

The result, as given above, shows very little difference in cost

per car mile, and if the pressure at the engines were 140 lbs., as required by the contract for the engines, we estimate that at least 6% would be saved in steam, and, therefore, in fuel oil, which would bring the total cost per car mile down to $.01615 for the Westinghouse plant as compared with $.016398 for the No. 1 plant, or 1½% less.

In considering the relative adaptability of the two systems to street railway work it should be remembered that the subdivided system allows of the shutting down of one or more engines when not needed, as during the slack time in the forenoon, middle afternoon, and evening. This would be felt in economy more when the plant was in full operation than under present conditions.

Another matter which cannot help affecting economy is the very rapid regulation of the smaller engines, thus adapting themselves more readily to variations in load than is possible with the engines of the Corliss type. In a regulation test, October 26, 1892, it was found that the governors on the Westinghouse engines were able to change from a very heavy load to a mere friction load within four revolutions, or one second of time.

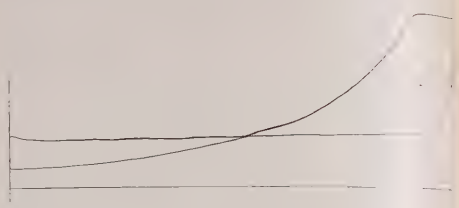
MISCELLANEOUS DATA AS TO CARS, PASSENGERS, HORSE-POWER PER CAR, ETC.

Average ratio of moving cars to total cars on the road, Test No. 1, Minneapolis	.81
Same, Test No. 2, St. Paul	.73
Average number of cars in use, Test No. 1, Minneapolis	116.7
Maximum at any time—6.20 P.M.—Test No. 1, Minneapolis	166.
Average number of cars in use, Test No. 2, St. Paul	55.
Maximum at any time—6.30 P.M.—Test No. 2, St. Paul	79.
Average horse-power per moving car, Test No. 1, Minneapolis	12.56
Greatest average horse-power per moving car, Test No. 1, Minneapolis, between 6.10 A.M. and 9.10 P.M., while 100 or more cars were running	13.31
Average horse-power per moving car, Test No. 2, St. Paul	25.71
Greatest average horse-power per moving car, Test No. 2, St. Paul, between 6.30 A.M. and 10.40 P.M., while 40 or more cars were running	27.85
Average number of passengers per car, Test No. 1, Minneapolis	9.33
Maximum average at any period	16.22
Average number of passengers per car, Test No. 2, St. Paul	4.95
Maximum average of passengers per car, Test No. 2, St. Paul	12.98
Maximum number of passengers in any car, Test No. 1, Minneapolis, 6.30 P.M.	61.
Same, Test No. 2, St. Paul, 6.20 P.M.	48.

Fig. 397.

No. 77. St. Paul, March 23, 1892.

Head End. H. P. No. 3. 80 S.



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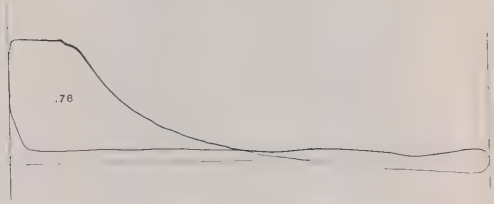

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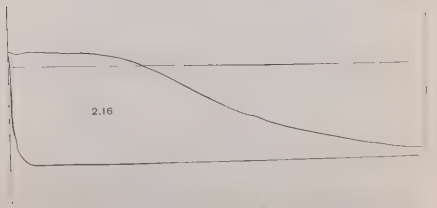
Crank End. I. P. No. 3. 30 S.



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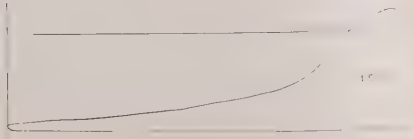

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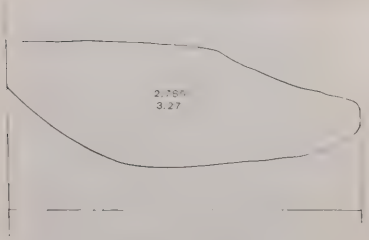
No. 70. Westinghouse—Compound Thirty-first Street. Minneapolis October 26, 1892.



H. P. No. 3. 80 S.

L. P. No. 3. 20 S.

DESCRIPTION OF ILLUSTRATIONS.

Fig. 387 is a graphical representation of the mechanical and electrical horse-power as calculated for each of the stated ten-minute intervals of Test No. 1, at Minneapolis; it also shows the number of moving cars at each of these periods, and also passengers on these cars.

Figs. 388 and 389 also represent the total number of cars, number of moving cars, and number of passengers on each. These three plates are inserted as giving a ready means of studying, in this case, whatever connection there may be between power and cars and passengers carried by them.

Figs. 390 to 393 represent combined diagrams of one of the St. Paul engines, with the hyperbolic curve drawn in, and also the curve represented by $pv^{1.0} = C$. These cards were selected at times when the variation in load was comparatively slight, and are presented to show the effect, on curves of expansion, of the steam-jackets.

Fig. 394 is a chart for reducing steam to its equivalent, "from and at 212°." In reducing the results of these tests, it was found convenient to use a chart designed by one of the writers, by which the constant, for reducing steam at any pressure evaporated from feed water at any temperature, could be obtained quickly.

In this chart (Fig. 394) the feed-water temperature is measured by horizontal distances or abscissæ, and the constant is given by ordinates to the inclined lines giving the various pressures. In the chart here presented the range shown is from 60° to 200° for feed water temperatures, and from 50 lbs. to 200 lbs. gauge pressure. The constant being calculated (for each pressure line desired) for the extremes of temperature—in this case, 60° and 200°—these constants are laid off on vertical lines through the points on the base indicating the temperatures, and a straight line drawn between. As these constants, for any given pressure, increase directly with the feed-water temperature, it will be seen that for any intermediate temperature the constant will be measured by the ordinate or distance from the base, at the point representing the temperature, to the line representing the pressure.

Fig. 395 is a graphical "log" of most of the data of Test No. 1.

Figs. 396 and 397 show sample sets of indicator cards from Tests Nos. 1, 2, and 3*b*.

TABLE I.

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—FUEL-OIL RECORD.

Time.	Wt. No. 1, full.	Wt. No. 1, emp.	Wt. No. 2, full.	Wt. No. 2, emp.	Wt. sent No. 3.	Temp., No. 3.	Time.	Wt. No. 1, full.	Wt. No. 1, emp.	Wt. No. 2, full.	Wt. No. 2, emp.	Wt. sent No. 3.	Temp., No. 3.
A.M.						Deg.							Deg.
4.15	1,206	132.5	.....	.....	1,073.5	98	3.00	.....	.....	1,209.5	171	1,038.5	106
4.30	.....	.....	1,068	180	888	96	3.30	1,257.5	152.5	.....	.....	1,105	108
5.40	1,229.5	149.5	.....	.....	1,080	96	4.00	.....	.....	1,222	183	1,039	106
6.20	.....	.....	1,153	176.5	976.5	95	4.30	1,210	153	.....	.....	1,057	106
6.50	1,277.5	141.5	.....	.....	1,136	100	5.00	.....	.....	1,257	175	1,082	105
7.20	.....	.....	1,189	177	1,012	99	5.30	1,248	143.5	.....	.....	1,104.5	106
7.40	1,275	153	.....	.....	1,122	99	6.00	.....	.....	1,246.5	173.5	1,073	105
8.10	.....	.....	1,212	175	1,037	100	6.30	1,220	140	.....	.....	1,080	103
8.30	1,324	177	.....	.....	1,147	98	7.00	.....	.....	1,234	172.5	1,061.5	100
9.00	.....	.....	1,215	167	1,048	99	7.30	1,288.5	151	.....	.....	1,137.5	100
9.20	1,303	146	.....	.....	1,157	103	7.50	.....	.....	1,246	172	1,074	100
9.50	.....	.....	1,229	178	1,051	106	8.30	1,217	138	.....	.....	1,079	100
10.20	1,250	156	.....	.....	1,094	106	9.00	.....	.....	1,237.5	173	1,064.5	98
11.00	.....	.....	1,204	176.5	1,027.5	106	9.20	1,267	145.5	.....	.....	1,121.5	100
11.30	1,265	168	.....	.....	1,097	106	10.00	.....	.....	1,264	172	1,092	98
M.													
12.00	.....	.....	1,209	190.5	1,018.5	105	10.40	1,215.5	148	.....	.....	1,067.5	98
12.30	1,250	150	.....	.....	1,100	106	11.10	.....	.....	1,282.5	191	1,091.5	96
1.00	.....	.....	1,220.5	173	1,047.5	106	12.00	1,316.5	141.5	.....	.....	1,175	98
1.30	1,255	175.5	.....	.....	1,079.5	106	12.40	.....	.....	1,229	173	1,056	96
2.00	.....	.....	1,205.5	186.5	1,019	106	1.30	1,275	133.5	.....	.....	1,141.5	98
2.30	1,275.5	140.5	.....	.....	1,135	106	1.50	.....	.....	1,223	1,064	159	.....

Total oil.....44,245.5 lbs.
Average temperature.....101.7°

TABLE II.

Test No. 1, Minneapolis, March 5, 1892—Feed-water Record.

Feed Water.							Feed Water.						
Time.	Wt. No. 1, full.	Wt. No. 1, emp.	Wt. No. 2, full.	Wt. No. 2, emp.	Wt. sent No. 3.	Temp., No. 3.	Time.	Wt. No. 1, full.	Wt. No. 1, emp.	Wt. No. 2, full.	Wt. No. 2, emp.	Wt. sent No. 3.	Temp., No. 3.
						Deg.							Deg.
4.10	.....	.....	4,592	710	3,882	70	3.10	4,920	555	.....	.....	4,365	130
4.40	4,800	680	.....	.....	4,120	71	3.15	.....	.....	4,890	485	4,405	.....
5.10	.....	.....	4,720	655	4,065	98	3.20	4,895	595	.....	.....	4,300	130
6.00	5,145	625	.....	.....	4,520	105	3.30	.....	.....	4,965	520	4,445	130
6.10	.....	.....	4,730	595	4,135	120	3.40	5,170	500	.....	.....	4,670	130
6.30	4,725	745	.....	.....	3,980	122	3.50	.....	.....	4,770	765	4,005	130
6.40	.....	.....	4,775	675	4,100	123	4.00	5,110	815	.....	.....	4,295	130
6.50	5,045	850	.....	.....	4,195	126	4.10	.....	.....	5,070	460	4,610	128
7.00	.....	.....	4,980	485	4,495	128	4.20	4,790	620	.....	.....	4,170	128
7.10	4,870	775	.....	.....	4,155	128	4.30	.....	.....	5,020	485	4,535	130
7.15	.....	.....	4,700	440	4,260	.....	4.40	5,270	570	.....	.....	4,700	128
7.20	4,715	585	.....	.....	4,130	129	4.50	.....	.....	5,210	550	4,660	126
7.25	.....	.....	4,930	640	4,350	.....	5.00	5,085	715	.....	.....	4,370	122
7.30	4,845	1,100	.....	.....	3,745	130	5.10	.....	.....	5,110	715	4,395	124
7.35	.....	.....	4,925	545	4,380	.....	5.30	5,055	935	.....	.....	4,120	130
7.40	4,755	575	.....	.....	4,180	130	5.35	.....	.....	5,070	465	4,605	.....
7.50	.....	.....	4,860	470	4,390	130	5.40	5,175	1,225	.....	.....	3,950	130
8.00	5,100	790	.....	.....	4,310	134	5.50	.....	.....	5,240	660	4,580	126
8.10	.....	.....	4,940	755	4,185	134	6.00	4,965	485	.....	.....	4,480	130
8.20	5,105	663	.....	.....	4,442	133	6.10	.....	.....	5,125	825	4,300	130
8.30	.....	.....	5,075	750	4,325	133	6.20	5,270	985	.....	.....	4,285	132
8.35	5,145	505	.....	.....	4,580	.....	6.30	.....	.....	5,055	1,400	3,655	130
8.40	.....	.....	5,400	600	4,800	132	6.35	5,375	895	.....	.....	4,570	.....
8.50	5,060	750	.....	.....	4,310	132	6.40	.....	.....	4,755	645	4,110	130
9.00	.....	.....	4,750	510	4,240	130	6.50	4,565	675	.....	.....	3,890	130
9.10	5,230	3,580	.....	.....	1,650	134	7.00	.....	.....	4,850	660	4,190	130
9.15	3,580	750	.....	.....	2,830	.....	7.05	5,080	660	.....	.....	4,420	130
9.15	.....	.....	4,995	635	4,360	128	7.10	.....	.....	4,815	960	3,855	130
9.25	5,175	625	.....	.....	4,550	.....	7.20	5,215	920	.....	.....	4,295	130
9.30	.....	.....	4,405	515	3,890	130	7.30	.....	.....	4,665	645	4,020	130
9.35	5,005	735	.....	.....	4,270	.....	7.40	5,130	950	.....	.....	4,180	130
9.40	.....	.....	4,950	740	4,210	128	7.50	.....	.....	5,050	600	4,450	130
9.45	5,240	685	.....	.....	4,555	.....	7.55	4,100	530	.....	.....	3,570	.....
9.50	.....	.....	5,010	635	4,375	128	8.00	.....	.....	4,425	475	3,950	126
10.10	4,985	710	.....	.....	4,275	128	8.05	5,085	1,162	.....	.....	3,873	.....
10.15	.....	.....	5,000	690	4,310	.....	8.10	.....	.....	5,050	1,067	3,983	126
10.30	5,185	1,560	.....	.....	3,625	130	8.20	5,065	730	.....	.....	4,335	123
10.35	.....	.....	5,280	585	4,695	.....	8.30	.....	.....	5,087	505	4,582	121
10.40	4,995	775	.....	.....	4,220	130	8.40	5,297	1,975	.....	.....	3,322	120
11.00	.....	.....	5,355	615	4,740	130	8.45	.....	.....	5,375	1,043	4,332	.....
11.10	5,065	1,960	.....	.....	3,105	132	8.50	5,200	750	.....	.....	4,470	122
11.20	.....	.....	5,285	670	4,615	.....	9.00	.....	.....	4,590	575	4,015	122
11.30	4,970	785	.....	.....	4,185	132	9.10	5,115	805	.....	.....	4,310	122
11.40	.....	.....	4,985	695	4,290	134	9.20	.....	.....	5,055	825	4,230	122
11.50	5,160	720	.....	.....	4,440	132	9.30	5,200	555	.....	.....	4,645	111
12.00	.....	.....	5,065	760	4,305	132	9.40	.....	.....	4,970	675	4,295	112
12.10	5,320	510	.....	.....	4,810	132	9.50	5,060	800	.....	.....	4,260	116
12.20	.....	.....	4,950	1,010	3,940	130	10.10	.....	.....	5,120	645	4,475	120
12.25	5,200	705	.....	.....	4,495	.....	10.20	5,085	620	.....	.....	4,465	120
12.30	.....	.....	4,910	440	4,770	130	10.30	.....	.....	5,000	580	4,420	118
1.00	5,200	1,495	.....	.....	3,705	123	10.50	5,260	1,315	.....	.....	3,945	122
1.05	.....	.....	5,280	640	4,640	.....	11.00	.....	.....	5,030	700	4,330	122
1.05	5,240	690	.....	.....	4,550	.....	11.10	5,135	542	.....	.....	4,593	120
1.10	.....	.....	5,155	865	4,290	134	11.30	.....	.....	4,745	690	4,055	117
1.20	5,235	865	.....	.....	4,370	130	11.50	5,100	1,490	.....	.....	3,610	114
1.40	.....	.....	5,205	705	4,500	133	12.00	.....	.....	4,980	655	4,325	116
1.50	5,090	730	.....	.....	4,360	132	12.10	4,925	615	.....	.....	4,310	116
2.00	.....	.....	4,925	565	4,360	132	12.20	.....	.....	4,430	715	3,715	116
2.10	5,240	655	.....	.....	4,385	130	12.30	5,215	1,130	.....	.....	4,085	114
2.20	.....	.....	5,180	770	4,410	130	12.40	.....	.....	5,230	660	4,570	116
2.30	5,210	620	.....	.....	4,590	130	12.50	5,055	522	.....	.....	4,533	114
2.40	.....	.....	4,940	605	4,335	128	1.00	.....	.....	5,250	590	4,660	112
2.50	5,225	1,440	.....	.....	3,785	128	1.10	5,245	1,090	.....	.....	4,155	109
3.00	.....	.....	5,195	650	4,545	130							

Total water.....525,487 lbs.
Average temperature.....123.4°

TABLE III.

Test No. 1, Minneapolis, March 5, 1892—General Boiler-room Record.

Time.	Steam pressure.		Water Levels.					Pyrometer 1.	Pyrometer 2.	Barometer.	Draught gauge.	Temperature of boiler room.
	Babcock & Wilcox.	Stirling.	1	3	4	5	7					
4.15	107.	98½	5½	7⅝	6⅜	7½	2½	320	340	.....	.....	.....
4.20	111.	91½	6½	9	9	6½	6⅜	.....	.....	.....	.....	.....
4.30	111.	109½	6	8½	7⅜	6	5	335	335	29.06	⅛	.....
4.40	118.	118½	6	8	8	6½	5½	.....	.....	.....	.....	.....
4.50	116.	98½	8⅜	8⅝	8⅝	9	5	.....	.....	.....	.....	.....
5.00	118.	117⅞	7⅝	7¼	7	6	9	350	345	.....	½	85
5.10	121.	118½	7⅝	7⅞	8	4⅜	8	.....	.....	.....	.....	.....
5.20	116.	116⅜	8⅜	8	9½	9⅜	8	.....	.....	.....	.....	.....
5.30	113.	117⅜	8½	8½	8½	9	7⅝	355	350	.....	¾	.....
5.40	119.	120½	7½	10	7	8	9	.....	.....	.....	.....	.....
5.50	120.4	120⅞	6	8½	6	7	9	.....	.....	.....	.....	.....
6.00	122.2	123¾	5⅝	10	4⅜	5½	6½	370	370	28.79	⅝	88
6.10	118.4	115⅜	7	8⅜	8½	6	3½	.....	.....	.....	.....	.....
6.20	119.8	pump broke	6½	8½	6⅝	7¾	stopped	.....	.....	.....	.....	.....
6.30	122.2	.....	8	6	6	7⅞	.....	390	375	.....	¾	.....
6.40	123.5	.....	5	3½	6	4⅛	.....	.....	.....	.....	.....	.....
6.50	123.5	.....	3⅜	6	3⅜	4	.....	.....	.....	.....	.....	.....
7.00	121.	.....	4⅜	6	6	3⅜	.....	390	375	28.82	⅛	92
7.10	124.5	.....	4⅜	3½	5½	5½	.....	.....	.....	.....	.....	.....
7.20	123.	.....	7⅜	6½	6	4⅜	.....	.....	.....	.....	.....	.....
7.30	120.5	.....	6	4⅜	9	6½	.....	390	375	.....	¾	.....
7.40	125.	.....	4½	6⅝	6⅜	7	.....	.....	.....	.....	.....	.....
7.50	124.	.....	8	8½	7⅜	5	.....	.....	.....	.....	.....	.....
8.00	122.5	.....	4⅜	4⅜	6⅛	8½	.....	385	370	28.88	¼	84
8.10	125.	.....	4½	7⅜	5⅛	5	.....	.....	.....	.....	.....	.....
8.20	120.	.....	7	5⅜	6⅛	5½	.....	.....	.....	.....	.....	.....
8.30	128.3	.....	4⅜	4½	5½	6⅜	.....	375	365	.....	¾	.....
8.40	120.6	.....	6½	6½	5½	4½	.....	.....	.....	.....	.....	.....
8.50	123.	.....	4½	4½	6½	8⅜	.....	.....	.....	.....	.....	.....
9.00	120.5	.....	6⅜	6⅜	5½	4⅜	.....	350	375	28.87	¾	82
9.10	125.5	.....	6½	3⅜	6½	6⅛	.....	.....	.....	.....	.....	.....
9.20	125.	121⅛	3⅜	9	8⅜	6⅜	12	.....	.....	.....	.....	.....
9.30	124.	126¾	8½	7⅜	6	7½	10½	385	395	.....	¾	.....
9.40	130.	129¾	9	6	6	7	8	.....	.....	.....	.....	.....
9.50	126.5	129¾	7½	9½	7⅜	5½	8⅜	.....	.....	.....	.....	.....
10.00	120.	127½	6⅜	6⅜	5	9	8	390	385	28.87	¾	72
10.10	124.5	128⅜	7	7⅜	9½	6½	7⅜	.....	.....	.....	.....	.....
10.20	127.5	129⅜	9⅜	8⅜	6½	7	8	.....	.....	.....	.....	.....
10.30	123.	130¾	7	9½	9⅜	6½	8½	400	390	.....	¼	.....
10.40	123.7	125¾	6	8⅜	7⅛	7	8⅜	.....	.....	.....	.....	.....
10.50	125.5	130¾	7	6	5½	6	8	.....	.....	.....	.....	.....
11.00	124.	127¼	6	6⅜	9½	6⅜	8½	405	395	28.84	¼	90
11.10	123.8	129¼	6	7⅛	7⅜	5½	8⅜	.....	.....	.....	.....	.....
11.20	125.	127½	8½	6½	7	4	9⅜	.....	.....	.....	.....	.....
11.30	123.5	127½	7	6	6	5	8½	385	390	.....	¾	.....
11.40	122.5	127¼	4½	5½	6⅜	9	8½	.....	.....	.....	.....	.....
11.50	124.3	129¾	5	5⅜	4⅜	7⅜	8	.....	.....	.....	.....	.....
12.00	126.5	127¼	8	8½	5⅜	6½	8	415	395	28.83	½	82
12.10	124.5	127½	6½	6½	8½	9	7	.....	.....	.....	.....	.....
12.20	125.	126½	7	5½	5	8	7½	.....	.....	.....	.....	.....
12.30	124.	130½	6½	8⅜	8	8	7½	405	390	.....	¼	.....
12.40	126.	126½	6	7⅜	6½	6½	7½	.....	.....	.....	.....	.....
12.50	121.5	127½	6	6	6	6½	7½	.....	.....	.....	.....	.....
1.00	128.	127½	6⅜	5⅜	6½	6⅜	7⅜	405	392	28.80	¼	82
1.10	126.	129⅜	6	7	6⅜	7½	8½	.....	.....	.....	.....	.....
1.20	126.	131½	7½	7	7	7	8½	.....	.....	.....	.....	.....
1.30	128.	126½	6½	7	6	7½	8	410	390	.....	¼	.....
1.40	123.	129¾	5⅜	8½	6½	6½	7½	.....	.....	.....	.....	.....
1.50	121.	125½	6	7½	6	7	7	.....	.....	.....	.....	.....
2.00	128.5	131½	6½	6½	6½	7⅜	7	410	398	28.79	¼	80
2.10	125.	126½	7½	7⅜	7⅜	6⅜	6½	.....	.....	.....	.....	.....
2.20	123.5	130¼	6½	6½	7	7¼	6⅜	.....	.....	.....	.....	.....
2.30	122.	129½	6½	6½	7	6	7½	410	395	.....	¼	.....
2.40	124.5	125½	5½	5½	6½	5⅜	8½	.....	.....	.....	.....	.....
2.50	120.5	126¾	6½	5	6⅜	6	8⅜	.....	.....	.....	.....	.....

TABLE III.—*Continued.*

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—GENERAL BOILER-ROOM RECORD.

Time.	Steam Pressure.		Water Levels.					Pyrometer 1.	Pyrometer 2.	Barometer.	Draught gauge.	Temperature of boiler room.
	Babcock & Wilcox.	Stirling.	1	3	4	5	7					
3.00	127.5	120⅝	4½	6¼	6⅝	8	8⅝	415	400	28.78	⅝	92
3.10	124.7	128⅝	6⅜	9⅜	6⅞	7⅜	7⅞	.....	.....	.....	.....	.....
3.20	124.5	130⅝	6	6½	6⅞	4⅜	7⅞	.....	.....	.....	.....	.....
3.30	120.	126⅞	6¼	7⅜	7⅛	8	7⅜	415	398	.....	⅝	.....
3.40	126.	123⅜	5¼	8¼	6½	9½	8	.....	.....	.....	.....	.....
3.50	122.	126⅜	6	7⅜	6¼	7	7⅞	.....	.....	.....	.....	.....
4.00	121.	125⅝	4⅛	7¼	6⅜	8	8	410	400	28.76	¾	88
4.10	125.	126⅛	9	5⅛	6¼	5¼	7⅛	.....	.....	.....	.....	.....
4.20	122.5	132⅜	7¾	7⅜	5½	6	7½	.....	.....	.....	.....	.....
4.30	123.5	128⅛	5⅜	10	10	8	7½	420	400	.....	¾	.....
4.40	124.5	126⅞	10	8⅜	8¼	6	7⅜	.....	.....	.....	.....	.....
4.50	126.5	130⅜	8⅝	5¾	6⅜	8¼	7⅜	.....	.....	.....	.....	.....
5.00	126.	125⅝	7	8	7⅜	6	8	415	405	28.74	¾	88
5.10	125.5	133½	5¾	8⅜	6⅜	6	9⅜	.....	.....	.....	.....	.....
5.20	124.5	130⅜	5¾	7	6½	5	8½	.....	.....	.....	.....	.....
5.30	124.	127⅛	5⅜	5¼	6	6⅜	8¼	415	403	.....	¾	.....
5.40	123.5	130⅜	5⅜	7⅜	6¼	6⅜	8	.....	.....	.....	.....	.....
5.50	123.5	128⅜	5⅜	6	6	6¼	7⅜	.....	.....	.....	.....	.....
6.00	122.5	129¼	5⅜	6	6	5¼	8	420	400	28.76	¾	84
6.10	120.	122⅛	4⅜	7⅜	5¼	6⅛	7	.....	.....	.....	.....	.....
6.20	126	129⅜	5	6	6⅜	6¼	7½	.....	.....	.....	.....	.....
6.30	127.	128¼	5¼	6	6	5½	7½	430	405	.....	¾	.....
6.40	122.	125½	3½	8⅜	4½	8½	.....	.....	.....	.....	.....	.....
6.50	126.	125½	5	10	6	6⅜	.....	.....	.....	.....	.....	.....
7.00	124.	128½	5⅛	8⅜	5	3	.....	420	405	28.77	¾	80
7.10	125.5	128⅜	7¼	7	6	8⅜	7	.....	.....	.....	.....	.....
7.20	129.	130⅜	4⅝	7½	5½	8⅜	6⅜	.....	.....	.....	.....	.....
7.30	119.	128⅜	7	7⅜	9	6	7	450	398	.....	¾	.....
7.40	132.	128¼	7½	5	6¼	4⅜	7¼	.....	.....	.....	.....	.....
7.50	123.	127⅛	7	9¼	4⅜	4	7⅛	.....	.....	.....	.....	.....
8.00	118.5	129⅜	4	7	10	10	7½	420	407	28.78	¾	78
8.10	119.	130⅜	7⅛	7⅜	9	6½	8	.....	.....	.....	.....	.....
8.20	124.5	129¼	8	7½	7⅜	5	8	.....	.....	.....	.....	.....
8.30	124.5	127⅛	7¼	5⅜	8⅜	6	8	420	405	.....	¾	.....
8.40	123.5	130⅜	6	8¼	7¼	8	8	.....	.....	.....	.....	.....
8.50	126.	128⅜	7	9⅜	8⅜	3⅜	8	.....	.....	.....	.....	.....
9.00	128.	126⅛	9	6	6⅜	5¼	8	415	403	28.78	¾	78
9.10	116.	132⅛	6⅜	6⅜	9	6	8	.....	.....	.....	.....	.....
9.20	126.	128⅜	6	6	6	6	8	.....	.....	.....	.....	.....
9.30	123.	129⅜	7¼	6	8	6	8	415	392	.....	¾	.....
9.40	120.	131¼	9½	6¼	7⅜	9½	7¼	.....	.....	.....	.....	.....
9.50	124.5	129¼	7⅛	6⅜	6⅜	8⅜	7⅛	.....	.....	.....	.....	.....
10.00	125.	127⅛	5⅜	6	6⅜	7¼	7⅛	420	385	28.78	¾	76
10.10	122.	129⅜	6	6⅜	7	6¼	7⅛	.....	.....	.....	.....	.....
10.20	122.5	130⅛	5	6⅜	5⅜	4⅜	7	.....	.....	.....	.....	.....
10.30	121.	129¼	4⅜	5¼	6	4⅜	7¼	415	385	.....	¾	.....
10.40	122.	127⅛	5⅜	2⅜	6⅜	6	8⅛	.....	.....	.....	.....	.....
10.50	122.5	130⅛	8⅛	6	6	6⅛	8⅛	.....	.....	.....	.....	.....
11.00	127.	128⅜	7	6¼	6⅜	5⅜	8	415	385	28.78	¾	76
11.10	124.	126⅛	6	5⅜	6	7⅛	7¼	.....	.....	.....	.....	.....
11.20	123.3	132⅜	6	5⅜	6	7	7⅛	.....	.....	.....	.....	.....
11.30	121.5	128⅜	6	6	6¼	5⅛	8¼	410	385	.....	¾	.....
11.40	116.	129¼	6	5⅛	6¼	4⅞	8½	.....	.....	.....	.....	.....
11.50	110.2	126⅞	6	4⅜	5⅜	5⅜	8⅜	.....	.....	.....	.....	.....
12.00	120.5	129⅞	5	4⅜	6	6	9	390	375	28.84	¾	.....
12.10	113.	125⅛	6⅜	6⅜	6	6½	8½	.....	.....	.....	.....	.....
12.20	110.	114⅜	7	8	7⅜	6⅜	8½	.....	.....	.....	.....	.....
12.30	112.5	114⅜	6⅜	6⅞	8⅜	7¼	9½	400	380	.....	¾	.....
12.40	118.	119⅜	9	5⅜	7⅜	5	9	.....	.....	.....	.....	.....
12.50	120.	119⅜	5⅜	7¼	6	5⅛	9½	.....	.....	.....	.....	.....
1.00	123.	119⅜	6⅛	6	7¼	6⅜	9⅜	400	380	28.85	¾	76
1.10	126.	114⅜	6	8⅛	9	8⅜	8	.....	.....	.....	.....	.....
1.20	125 5	90⅜	6¼	7¼	9	9⅜	8⅜	.....	.....	.....	.....	.....
1.30	127.	114⅜	9	5⅜	8	9⅜	8	365	362	.....	¾	.....
1.40	118.5	95⅜	7¼	5⅛	7¼	9	7⅜	.....	.....	.....	.....	.....
1.50	110.	91⅜	7¼	5⅜	7⅜	8	9	.....	.....	.....	.....	.....
Av.....	122.4								385	28.77	¾	82.5

TABLE IV.

TEST NO. 1, MINNEAPOLIS, MARCH, 5, 1892—STEAM AND VACUUM GAUGES IN ENGINE ROOM, ALSO ENGINE SPEEDS.

	Engine No. 2.					Engine No. 1.				
Time.	Gauges.			Vacuum.	Speed.	Gauges.			Vacuum.	Speed.
	H.P.	I. P.	L. P.			H. P.	I. P.	L. P.		
4.20	109	39.8	0.0	24.9	.....	.....	.....	.....	.....	.....
4.30	110	29.3	0.0	24.9	63.6	.....	.....	.....	.....	.....
4.40	115	30.0	−1.8	24.9	64.7	.....	.....	.....	.....	.....
4.50	114	29.8	−1.8	24.9	62.8	.....	.....	.....	.....	.....
5.00	115	30.5	−0.8	24.9	63.7	.....	.....	.....	.....	.....
5.10	118	31.7	−0.8	24.9	64.	.....	.....	.....	.....	.....
5.20	113	29.9	0.0	24.9	64.1	.....	.....	.....	.....	.....
5.30	111	29.3	−5.0	24.9	63.4	.....	.....	.....	.....	.....
5.40	116	31.0	−0.8	24.7	63.4	.....	.....	.....	.....	.....
5.50	118	30.9	−5.	24.8	63.	116	30.7	−2.0	25.1	.....
6.00	119	31.8	−2.8	24.5	63.8	117	31.7	−3.5	25.	.....
6.10	115	30.6	−1.8	24.3	64.	115	31.7	0.0	24.8	61.4
6.20	117	30.8	+1.0	24.	62.1	117	32.7	+1.0	24.6	62.2
6.30	118	31.6	0.0	23.8	63.2	118	31.2	+2.0	24.2	62.1
6.40	120	32.3	−3.9	23.6	62.6	119	31.2	−1.0	24.2	61.8
6.50	120	31.8	−2.8	23.6	62.7	119	31.8	−1.0	24.2	62.2
7.00	118	31.3	−3.9	23.7	63.5	116	31.2	−4.0	24.3	63.5
7.10	121	32.2	−0.8	23.6	62.5	119	31.2	−2.0	24.4	62.5
7.20	119	31.7	0.0	23.7	62.5	117	31.2	−3.0	24.2	61.6
7.30	117	31.2	−2.3	23.8	63.9	116	30.8	−3.0	24.2	62.9
7.40	122	32.6	0.0	23.7	62.1	121	32.1	−2.0	24.2	61.5
7.50	122	32.3	0.0	23.7	63.3	118	31.5	−5.0	24.3	64.5
8.00	119	31.6	−0.8	23.9	61.8	119	31.1	−4.0	24.4	60.4
8.10	122	31.5	−0.8	23.6	62.9	121	31.7	−1.0	24.1	61.6
8.20	120	30.6	−3.9	23.9	64.3	116	29.4	0.0	24.	64.5
8.30	126	31.9	−2.8	23.8	62.1	125	33.4	−1.0	24.2	61.6
8.40	118	29.9	−0.8	24.	62.7	117	30.8	−4.0	24.2	61.9
8.50	121	30.6	−1.8	23.5	63.2	117	31.4	−3.0	24.	63.1
9.00	118	29.8	−3.9	23.8	62.2	116	29.2	−1.5	24.	61.7
9.10	122	31.3	−3.9	24.	63.3	121	31.8	−2.5	23.9	62.5
9.20	122	31.7	−2.8	23.9	62.8	122	31.8	−3.	23.9	61.6
9.30	121	31.2	−2.8	23.6	63.2	120	31.8	−4.5	23.9	64.1
9.40	127	32.6	−2.8	23.6	63.	124	33.1	−3.	23.9	62.6
9.50	123	31.7	−5.5	24.1	63.4	124	32.8	+2.	23.5	62.8
10.00	117	30.6	0.0	25.1	62.7	116	29.8	−1.	23.7	62.9
10.10	122.5	32.3	−2.8	23.9	63.4	119	31.6	−3.	24.2	61.7
10.20	124	32.5	−1.8	23.6	62.6	126	32.7	−3.5	24.4	62.9
10.30	120	30.9	−0.8	23.5	62.1	119	30.2	−2.5	24.3	60.4
10.40	121	31.1	+0.5	23.6	63.3	120	31.3	−6.	24.3	63.7
10.50	122.5	31.0	−1.8	23.7	63.4	122	31.8	−2.	24.2	63.
11.00	121	30.8	−4.4	23.2	62.3	121	30.8	−3.	24.5	62.
11.10	121	31.0	−4.4	23.9	62.7	120	30.8	−5.9	24.4	62.8
11.20	122	31.0	−3.4	23.8	62.6	120	30.9	−4.	24.2	61.3
11.30	126	32.4	−3.9	24.2	63.6	123.5	31.9	−4.	24.5	64.
11.40	119	30.8	−1.3	23.9	62.6	119	31.3	−5.	24.4	61.3
11.50	122	30.3	0.0	23.9	63.	120	31.5	−3.	24.4	62.7
12.00	124	31.7	−1.8	23.9	62.1	122	31.9	−5.	24.3	62.1
12.10	121	31.3	−3.4	23.6	63.6	120	31.9	−4.5	24.2	62.8
12.20	122	31.9	−4.4	23.7	62.7	121	31.2	−2.	24.3	61.7
12.30	120	30.8	−0.2	23.9	62.5	119	30.7	−3.5	24.2	62.1
12.40	123	31.9	−1.8	23.7	62.9	122	31.8	−4.	24.2	62.2
12.50	118	30.4	0.0	23.9	62.8	119	30.3	−1.5	24.1	63.6
1.00	126	31.9	−1.3	23.7	62.9	124	29.9	−2.	24.2	62.3
1.10	123	31.8	−0.3	23.6	62.9	122	31.2	−3.	24.2	61.3
1.20	122	31.3	0.0	23.4	63.1	120	29.7	−3.	24.2	63.
1.30	126	32.	0.0	23.7	63.1	124	29.7	−2.5	23.9	63.7
1.40	120	30.9	−3.4	24.	63.3	119	27.6	−2.5	24.	61.8
1.50	118	29.8	−2.3	24.2	62.5	117	29.5	−2.	24.	62.3
2.00	127	32.8	−3.9	24.2	63.6	125	32.7	−1.	24.2	62.1
2.10	122	31.6	−3.4	24.1	62.9	122	31.4	−6.	24.4	63.
2.20	120	30.8	−5.5	24.3	62.8	119	30.9	−6.	24.2	61.1
2.30	118	30.3	−2.3	24.1	63.	118	30.2	−3.8	24.2	62.5
2.40	122	30.8	−1.3	24.	62.8	120	31.7	−3.	24.3	61.7
2.50	117	30.3	−0.8	23.6	63.5	119	30.7	−4.	24.3	63.

TABLE IV.—*Continued.*

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—STEAM AND VACUUM GAUGES IN ENGINE ROOM, ALSO ENGINE SPEEDS.

Time.	Engine No. 2.					Engine No. 1.				
	Gauges.			Vacuum.	Speed.	Gauges.			Vacuum.	Speed.
	H. P.	I. P.	L. P.			H. P.	I. P.	L. P.		
3.00	124	32.3	−4.4	23.2	62.7	124	33.7	−1.	24.2	63.8
3.10	122	31.6	−3.4	24.1	63.1	120	31.7	−5.	24.5	61.8
3.20	122	31.3	−1.8	23.9	64.2	121	31.9	−1.	24.5	62.4
3.30	117	30.3	−2.8	23.8	61.8	117	30.8	−4.	24.3	61.6
3.40	124	31.9	−1.3	23.8	62.6	121	32.7	−3.	24.5	62.7
3.50	122	31.6	−2.8	23.9	63.	119	31.8	+1.5	24.	62.3
4.00	123	31.9	0.0	24.	62.4	122	32.5	−3.	24.4	61.9
4.10	122.5	32.	−1.8	23.7	64.1	122	32.3	−1.	24.4	63.6
4.20	120	31.3	0.0	23.4	62.3	119	31.3	−4.	24.5	61.7
4.30	120	31.2	0.0	23.4	62.7	120	31.8	−2.8	24.3	62.2
4.40	122	31.3	0.0	23.9	62.7	119	32.0	−4.	24.3	62.8
4.50	123	32.	−1.8	23.4	63.3	123	32.7	−2.	24.4	63.1
5.00	123	31.9	+0.5	23.5	62.9	122	32.6	0.0	24.	62.6
5.10	122	32.	−3.7	23.5	63.2	121	32.6	−1.5	24.1	62.3
5.20	122	31.	+1.0	23.6	62.8	121	31.8	−2.	24.1	61.9
5.30	120	30.9	−1.8	23.5	62.8	119	31.6	+2.	23.9	63.3
5.40	120	30.3	0.0	23.6	62.9	120	31.5	−3.	23.9	62.1
5.50	120	30.7	+0.5	23.3	63.7	119	31.6	−3.	24.1	61.7
6.00	120	29.6	+2.9	23.6	61.7	119	31.	+1.	23.9	62.
6.10	117	29.3	0.0	23.4	62.8	117	30.6	0.0	23.7	62.5
6.20	123	31.3	0.0	23.2	62.9	120	31.7	−4	24.	62.4
6.30	125	31.8	−2.8	23.5	62.	123	32.7	−1.	24.	61.3
6.40	119	30.8	−0.8	23.8	62.3	118	31.2	+1.	23.8	61.8
6.50	123	30.8	0.0	23.6	63.1	119	32.1	−0.5	24.	63.
7.00	121	30.8	−0.8	23.7	62.9	120	31.7	−2.5	24.3	61.1
7.10	122	30.8	−3.4	24.	62.2	121	32.1	0.0	24.	63.3
7.20	125	31.8	−1.8	23.9	63.5	125	33.4	0.0	24.2	61.8
7.30	115	29.3	−3.9	23.9	62.3	113	29.7	0.0	23.8	61.7
7.40	130	32.8	−2.8	23.9	63.9	126	34.2	−1.5	24.2	63.8
7.50	120	30.3	0.0	24.1	62.5	119	31.9	+2.	23.9	61.4
8.00	115	29.3	−2.8	24.1	62.9	115	29.2	0.0	23.8	62.3
8.10	116	29.8	−5.0	24.1	62.5	114	30.2	−2.	24.	61.9
8.20	122	30.7	−1.8	24.	62.7	121	31.8	−4.	24.2	61.8
8.30	122	30.9	0.0	24.	62.6	121	32.3	−3.	24.6	63.7
8.40	121	31.3	0.0	24.4	64.2	120	31.9	−4.	24.5	61.8
8.50	124	32.8	+1.0	24.4	62.1	120	33.2	0.0	24.7	61.5
9.00	125	33.7	0.0	24.5	63.5	126	33.6	−1.	24.5	63.1
9.10	113	30.3	−0.3	24.4	63.1	112	29.8	−1.	24.8	64.2
9.20	122	32.8	−1.3	24.6	63.5	123	32.8	−4.	24.7	62.1
9.30	121	32.3	0.0	24.4	63.3	118	31.8	−3.	24.7	62.4
9.40	117	29.8	−1.3	24.4	63.3	116	30.5	−5.	24.9	63.4
9.50	121	31.8	0.0	24.5	63.	121	31.7	−4.	24.8	62.5
10.00	122	32.3	−5.0	24.4	63.4	122	32.7	−4.	24.8	62.9
10.10	120	31.18	−2.8	24.4	63.	118	32.	−2.	24.8	61.8
10.20	119	32.3	−3.9	24.5	63.2	119	32.2	−1.	24.8	62.3
10.30	119	31.3	0.0	24.2	63.2	117	31.8	0.0	24.8	63.7
10.40	118	31.3	−2.8	24.8	63.4	120	32.5	+2.	24.9	62.
10.50	119	32.	−1.8	24.7	63.7	119	31.7	−3.	24.9	65.5
11.00	124	32.8	−5.0	24.7	63.7	124	33.2	−2.	25.1	61.9
11.10	122	32.8	0.0	24.7	63.	120	32.9	0.0	24.9	61.7
11.20	120	31.3	0.0	24.4	63.1	119	32.5	0.0	24.9	63.2
11.30	118	30.8	−2.8	24.7	63.4	117	31.9	−1.5	25.	63.6
11.40	113	29.8	−0.8	24.6	63.7	111	30.7	−1.8	25.	62.1
11.50	113	27.8	+1.0	24.5	62.6	107	29.2	−2.	25.2	63.5
12.00	118	31.3	−0.8	24.6	62.9	117	32.7	+0.5	25.	62.3
12.10	112	29.8	+0.5	24.6	64.3	109	29.7	−2.	25.2	61.8
12.20	108	28.8	−2.8	24.7	63.7	107	29.2	−3.	25.2	63.7
12.30	110	29.3	−3.9	25.2	63.2	109	29.7	−3.	24.8	65.3
12.40	115	31.3	0.0	25.2	63.2	115	31.7	0.0	25.2	60.
12.50	117	32.3	0.0	25.4	63.2	116	31.8	−2.	25.2	61.5
1.00	Shut	down.				121	32.7	0.0	25.2	64.6
1.10						122	31.4	0.0	25.3	
1.20						122	33.2	+1.	25.4	63.7
1.30						124	33.7	−1.	25.5	63.1
1.40						115	31.2	−1.	25.4	63.4
1.50						107	32.7	0.0	25.7	53.
Av'ges.					63.					62.26

TABLE V.

Test No. 1, Minneapolis, March 5, 1892—Temperatures in Condensers, and Water collected from Jackets and Separators.

Condenser Temperatures.			Water from Separators and Jackets					
			Engine No. 1.			Engine No. 2.		
Time.	Temp. of Condensing Water.	Temp. of Hot Well No. 1.	Temp. of Hot Well No. 2.	From Separator.	From H. P., I. P., and Receiver.	From L. P. and Receiver.	From Separator.	From H. P., I. P., and Receiver.	From L. P. and Receiver.
	Deg. F.	Deg. F.	Deg. F.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
4.15 A.M.	35	...	66	.....	.....	.....	.....	.....	.....
4.30	35	.....	.....	.....	.....	.....	.....	.....	.....
4.40	35	.....	66	.....	.....	.....	.....	.....	.....
4.50	36	.....	66	.....	.....	.....	.....	.....	.....
5.00	36	.....	66	.....	.....	.....	.....	.....	.....
5.10	36	.....	66	.....	.....	.....	.....	.....	.....
5.17	36	.....	66	.....	.....	.....	.....	.....	.....
5.25	36	.....	66	.....	.....	.....	.....	.....	.....
5.35	36	61	84	.....	.....	.....	.....	.....	.....
5.45	36	61	79	No. 1 Eng. started at 5.40 A.M.			.....	.....	.....
5.55	36	66	84	129	221	.....	.....	.....	.....
6.10	36	72	91½	.....	.....	171	.....	.....	.....
6.20	36	79	95	.....	.....	.....	.....	.....	.....
6.25	.....	.....	.....	.....	259	.....	.....	.....	.....
6.30	36	88	88	.....	.....	.....	.....	.....	.....
6.40	36	88	90	221	188	154	Total to this time, 350	Total, 608	Total, 325
6.50	36	88	90	.....	.....	.....	.....	.....	.....
7.00	36	86	90	.....	231	.....	161.5	.....	.....
7.05	.....	.....	.....	.....	.....	.....	.....	.....	279.5
7.10	36	86	90	.....	.....	.....	.....	256	.....
7.15	.....	.....	.....	161	177	193	.....	.....	.....
7.20	36	88	90	.....	.....	.....	.....	.....	.....
7.30	36	93	91½	.....	.....	189	62	265.5	239
7.40	36	93	91½	.....	.....	.....	.....	.....	.....
7.45	.....	.....	.....	157	195	216	.....	.....	.....
7.50	36	93	89½	.....	.....	.....	.....	.....	.....
8.00	36	95	93	.....	.....	.....	.....	258	215
8.10	36	93	93	.....	.....	.....	.....	.....	.....
8.15	.....	.....	.....	134	307	200	.....	.....	.....
8.20	36	95	91½	.....	.....	.....	.....	.....	.....
8.30	36	95	93	.....	.....	.....	.....	410	326
8.40	36	93	91½	.....	.....	.....	.....	.....	.....
8.45	.....	.....	.....	.....	218	234	.....	.....	.....
8.50	36	93	93	.....	.....	.....	.....	.....	.....
9.00	36	95	93	196	.....	.....	.....	363	183
9.10	36	100½	89½	.....	.....	.....	.....	.....	.....
9.15	.....	.....	.....	.....	296	226	135	245	201
9.20	36	97	93	.....	.....	.....	.....	.....	.....
9.30	36	95	95	150	230	262	.....	.....	.....
9.40	36	100½	91½	.....	.....	.....	.....	.....	.....
9.50	36	107½	89½	.....	.....	.....	.....	.....	.....
9.55	.....	.....	.....	.....	.....	.....	.....	285	234
10.00	36	107½	93	124	276	211	.....	.....	.....
10.10	36	104	93	.....	.....	.....	.....	.....	.....
10.15	.....	.....	.....	.....	.....	.....	.....	256	260
10.20	36	100½	100½	.....	.....	.....	.....	.....	.....
10.30	36	100½	100½	142	291	248	.....	251	267
10.40	36	98½	98½	.....	.....	.....	.....	.....	.....
10.45	.....	.....	.....	.....	271	.....	.....	.....	.....
10.50	36	98½	98½	.....	.....	.....	.....	240.5	.....
11.00	36	100½	100½	155	215	296	.....	.....	230
11.10	36	97	98½	.....	.....	.....	.....	.....	.....
11.15	.....	.....	.....	.....	.....	.....	.....	279.5	.....
11.20	36	98½	97	.....	182	.....	.....	.....	.....
11.30	36	95	89½	177	.....	289	.....	214	284

TABLE V.—*Continued.*

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—TEMPERATURES IN CONDENSERS, AND WATER COLLECTED FROM JACKETS AND SEPARATORS.

Condenser Temperatures.			Water from Separators and Jackets.					
			Engine No. 1.			Engine No. 2.		
Time.	Temp. of Condensing Water.	Temp. of Hot Well No. 1.	Temp. of Hot Well No. 2.	From Separator.	From H. P. I. P., and Receiver.	From L. P. and Receiver.	From Separator.	From H. P. I. P., and Receiver.	From L. P. and Receiver.
	Deg. F.	Deg. F.	Deg. F.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
11.40 A.M.	36	95	89½	.....	.....	.....	.....	.....	.....
11.45	.....	.....	.....	.....	275	.....	.....	.....	.....
11.50	36	95	93	.....	.....	.....	.....	.....	.....
12.00 M.	36	95	93	138	148	291	.....	286	310
12.10 P.M.	36	100½	97	.....	.....	.....	.....	.....	.....
12.20	36	100½	93	.....	.....	.....	.....	.....	.....
12.30	36	100½	95	126	352	297	.....	344	292
12.40	36	100½	95	.....	.....	.....	.....	.....	.....
12.50	36	100½	95	.....	.....	.....	.....	.....	.....
				Totals to 1 P.M.			Totals to 1 P.M.		
				2,010	4,761	3,610	928.5	5,614	4,125.5
1.00	36	100½	95	165	386	311	320	301	253
1.10	36	100½	93	.....	.....	.....	.....	.....	.....
1.20	36	100½	97	.....	.....	.....	.....	.....	.....
1.30	36	100½	97	138	140	272	.....	328	.....
1.40	36	100½	97	.....	.....	.....	.....	.....	345
1.50	36	89½	95	.....	.....	.....	.....	.....	.....
1.55	.....	.....	.....	.....	.....	.....	.....	295	.....
2.00	35	82½	93	131	351	321	.....	.....	.....
2.10	36	86	93	.....	.....	.....	.....	.....	.....
2.15	.....	.....	.....	.....	.....	.....	.....	341	355.5
2.20	36	86	88	.....	.....	.....	.....	.....	.....
2.30	36	91½	93	229	304	301	.....	.....	.....
2.40	36	91½	91½	.....	.....	.....	.....	.....	.....
2.50	35	93	91½	.....	.....	.....	.....	307	317.5
2.55	.....	.....	.....	128	356	319	.....	.....	.....
				Totals to 3 P.M.			Totals to 3 P.M.		
				2,801	6,298	5,134	928.5	6,685	5,143.5
3.00	37	89½	89½	.....	.....	.....	.....	.....	.....
3.10	39	91½	91½	.....	.....	.....	.....	.....	.....
3.20	39	89½	89½	.....	.....	.....	.....	346	.....
3.30	39	89½	91½	170	314	324	.....	.....	.....
3.40	39	89½	91½	.....	.....	.....	.....	.....	.....
3.45	.....	.....	.....	.....	.....	.....	.....	295	361.5
3.50	40	89½	91½	.....	.....	.....	.....	.....	.....
4.00	39	89½	89½	136	329	278	.....	.....	.....
4.10	37	89½	93	.....	.....	.....	.....	.....	.....
4.20	36	89½	95	.....	.....	.....	.....	358	315
4.30	38	91½	97	132	302	282	283	.....	.....
4.40	37	91½	95	.....	.....	.....	.....	.....	.....
4.45	.....	.....	.....	.....	.....	.....	.....	290	308
4.50	38	93	93	.....	.....	.....	.....	.....	.....
5.00	39	95	95	136	374	286	.....	.....	.....
5.10	40	95	93	.....	.....	.....	.....	.....	.....
5.15	.....	.....	.....	.....	.....	.....	.....	303	342
5.20	39	95	93	.....	.....	.....	.....	.....	.....
5.30	38	94	95	167	362	324	.....	.....	.....
5.40	39	97	93	.....	.....	.....	.....	.....	.....
5.45	.....	.....	.....	.....	.....	.....	.....	284	.....
5.50	39	93	89½	.....	.....	.....	.....	.....	.....
				Totals to 6 P.M., incl.			Totals to 6 P.M., incl.		
				3,685	8,360	6,961	1,211.5	8,892	6,799
6.00	39	95	89½	143	381	333	.....	331	329
6.10	39	97	97	.....	.....	.....	.....	.....	.....

TABLE V.—*Continued.*

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—TEMPERATURES IN CONDENSERS, AND WATER COLLECTED FROM JACKETS AND SEPARATORS.

Condenser Temperatures.				Water from Separators and Jackets.					
				Engine No. 1.			Engine No. 2.		
Time.	Temp. of Condensing Water.	Temp. of Hot Well No. 1.	Temp. of Hot Well No. 2.	From Separator.	From H. P., I. P., and Receiver.	From L. P. and Receiver.	From Separator.	From H. P., I. P., and Receiver.	From L. P. and Receiver.
	Deg. F.	Deg. F.	Deg. F.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
6.20 P.M.	38	97	97	.....	.....	.....	.....	.....	.....
6.30	39	97	91½	.....	318	331	.....	353	318
6.40	38	95	89½	.....	.....	.....	.....	.....	.....
6.50	38	95	89½	.....	.....	.....	.....	.....	.....
7.00	36	93	88	209	334	306	.....	335	300
7.10	36	93	88	.....	.....	.....	.....	.....	.....
7.20	38	95	89½	.....	.....	.....	.....	.....	.....
7.30	36	91½	89½	140	333	314	.....	363	324
7.40	38	91½	89½	.....	.....	.....	.....	.....	.....
7.50	38	89½	87	.....	.....	.....	.....	.....	.....
8.00	36	98½	89	165	375	329	.....	348	319
8.10	38	97	84	.....	.....	.....	.....	.....	.....
8.20	37	86	88	.....	.....	.....	.....	.....	.....
8.30	38	86	86	132	344	337	349	316	250
8.40	38	86	82½	.....	.....	.....	.....	.....	.....
8.50	37	86	80½	.....	.....	.....	.....	.....	.....
				Totals to 9 P.M.			Totals to 9 P.M.		
				4,491	10,440	8,901	1,560.5	11,017	8,621
9.00	37	86	86	160	376	323	.....	410	311
9.10	36	82½	88	.....	.....	.....	.....	.....	.....
9.20	37	86	88	.....	.....	.....	.....	.....	.....
9.30	37	82½	88	136	347	241	.....	306	.....
9.40	35	80½	86	.....	.....	.....	.....	.....	.....
9.50	36	80½	86	.....	.....	.....	.....	.....	.....
10.00	36	80½	86	137	354	237	.....	344	359
10.10	35	82½	91½	.....	.....	.....	.....	.....	.....
10.20	37	80½	84	.....	.....	.....	.....	.....	.....
10.30	36	80½	86	140	332	243	.....	322	331
10.40	36	79	86	.....	.....	.....	.....	.....	.....
10.50	35	77	79	.....	.....	.....	.....	.....	.....
11.00	35	77	82½	199	327	211	.....	292	.....
11.10	35	82½	82½	.....	.....	.....	.....	.....	.....
11.20	35	80½	84	.....	.....	.....	.....	.....	.....
11.30	36	80½	84	108	257	188	.....	312	316
11.40	36	79	82½	.....	.....	.....	.....	.....	.....
11.50	36	79	82½	.....	.....	.....	.....	.....	.....
				Totals to 12 P.M., incl.			Totals to 12 P.M., incl.		
				5,350	12,302	10,214	1,560.5	12,919	9,627
12.00 M.	37	79	82½	139	245	193	.....	326	.....
12.10 A.M.	36	77	82½	.....	.....	.....	.....	.....	.....
12.20	36	79	80½	.....	.....	.....	.....	.....	.....
12.30	36	79	82½	.....	.....	.....	326.5	260	.....
12.40	35	71½	73½	.....	.....	.....	.....	.....	.....
12.45	.....	.....	.....	157	.....	.....	.....	.....	.....
12.50	35	75	73½	.....	.....	.....	.....	.....	.....
1.00	35	75	68	.....	293	251	19	94	262
1.10	35	64½	.....	.....	.....	.....	.....	.....	.....
1.20	35	64½	.....	.....	.....	.....	.....	.....	.....
1.30	35	61	.....	196	139	144	.....	.....	.....
1.40	37	62½	.....	.....	.....	.....	.....	.....	.....
1.50	.....	.....	No. 2 Condenser shut down.	75	106	104	.....	.....	.....
				5,778	13,104	10,873	1,896	13,263	9,889

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—WATER USED IN STIRLING BOILER FOR CONDENSER ENGINES, PUMPS, AND HEATING.

The water used in this boiler was weighed in a separate barrel, and as it was very uniform throughout the run, the table is omitted.

Also, it should be stated that the amount charged per hour is obtained from a run of sixteen hours and thirty-five minutes only, as, soon after starting, the feed-pump broke down and it took about three hours to replace it.

Total water used in Stirling boiler from 9.20 A.M., March 5, to 1.55 A.M., March 6, 1892	95,443 lbs.
Average water per hour	5,837.5 lbs.

TABLE VII.

TEST NO. 1, MINNEAPOLIS, MARCH 5, 1892—TABLE OF HORSE-POWER OF MAIN AND CONDENSER ENGINES.

Time.	Main engines.	Condenser engines.	Time.	Main engines.	Condenser engines.
4.20	117.00	7.67	3.50	1,353.08	15.11
4.30	231.07	7.60	4.00	1,532.52	14.92
4.40	230.91	8.17	4.10	1,443.68	15.37
4.50	197.03	7.05	4.20	1,379.09	14.86
5.00	147.76	6.82	4.30	1,594.51	14.45
5.10	195.33	6.89	4.40	1,442.37	12.82
5.20	195.57	6.82	4.50	1,456.40	14.80
5.30	227.24	7.06	5.00	1,492.34	15.09
5.40	418.11	6.42	5.10	1,732.60	14.68
5.50	527.32	16.08	5.20	1,526.13	13.64
6.00	832.69	16.44	5.30	1,436.72	13.76
6.10	979.66	15.57	5.40	1,529.09	13.86
6.20	1,267.38	15.95	5.50	2,046.19	14.04
6.30	930.06	16.31	6.00	1,928.72	10.53
6.40	1,537.33	15.19	6.10	1,832.39	10.62
6.50	1,541.91	15.81	6.20	1,930.99	10.05
7.00	1,496.20	14.41	6.30	1,518.80	11.88
7.10	1,150.73	15.72	6.40	1,530.78	10.32
7.20	1,354.74	15.07	6.50	1,823.71	14.60
7.30	1,470.54	14.85	7.00	1,755.80	13.79
7.40	1,398.82	15.69	7.10	1,643.45	15.40
7.50	1,652.95	14.99	7.20	1,896.95	13.64
8.00	1,270.68	14.58	7.30	1,494.29	13.73
8.10	1,371.67	15.24	7.40	1,457.27	13.95
8.20	1,484.30	15.08	7.50	1,841.59	14.00
8.30	1,441.74	15.07	8.00	1,794.40	14.11
8.40	1,405.52	15.97	8.10	1,215.45	14.51
8.50	1,589.41	14.59	8.20	1,632.70	13.93
9.00	1,241.55	14.80	8.30	1,624.83	14.28
9.10	1,412.01	14.36	8.40	1,431.89	15.28
9.20	1,316.28	14.55	8.50	1,442.17	14.95
9.30	1,476.87	15.00	9.00	1,145.15	13.50
9.40	1,538.97	13.67	9.10	1,179.85	12.98
9.50	1,290.75	15.36	9.20	1,104.27	12.81
10.00	1,035.36	14.44	9.30	1,091.71	13.90
10.10	1,455.18	14.01	9.40	971.58	13.92
10.20	1,402.78	13.62	9.50	1,230.88	13.47
10.30	1,493.02	13.48	10.00	961.21	14.50
10.40	1,364.24	12.46	10.10	986.28	13.47
10.50	1,392.99	14.02	10.20	955.61	13.72
11.00	1,295.67	13.05	10.30	1,238.59	14.02
11.10	1,344.92	12.67	10.40	877.63	12.79
11.20	1,489.29	13.30	10.50	1,194.19	13.35
11.30	1,383.00	15.21	11.00	886.23	12.54
11.40	1,241.01	12.39	11.10	1,003.42	14.47
11.50	1,566.41	15.04	11.20	1,112.65	13.20
12.00	1,326.25	14.26	11.30	1,055.51	13.42
12.10	1,437.95	14.81	11.40	1,081.00	13.14
12.20	1,298.45	14.40	11.50	1,053.57	12.80
12.30	1,321.09	14.94	12.00	790.62	13.66
12.40	1,329.05	15.10	12.10	1,016.92	14.13
12.50	1,385.59	15.15	12.20	851.99	13.08
1.00	1,376.78	13.72	12.30	834.45	12.77
1.10	1,428.39	13.51	12.40	430.76	12.74
1.20	1,505.50	13.45	12.50	634.02	12.36
1.30	1,527.77	14.25	1.00	443.44	12.95
1.40	1,397.92	13.88	1.10	448.92	12.11
1.50	1,451.33	13.50	1.20	262.15	7.11
2.00	1,470.78	13.10	1.30	281.55	6.56
2.10	1,301.96	15.00			
2.20	1,391.46	14.49	Average	1,237.4	Average as taken, 13.66 H.P.
2.30	1,484.63	13.31			
2.40	1,541.11	12.66			
2.50	1,568.11	14.69			Average as above, with a few vacant figures filled in, 13.47 H.P.
3.00	1,364.26	14.16			
3.10	1,185.07	15.39			
3.20	1,202.32	15.35			
3.30	1,473.92	15.29			
3.40	1,380.95	15.78			

TABLE VIII.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—FEED WATER AND OIL RECORD, ALSO GENERAL BOILER-ROOM RECORD.

Time.	Feed Water.		Oil Record.		Steam Gauges in Boiler Room, etc.								
	Weight to Tank 3.	Temp., Tank 3.	Weight to Tank 3.	Temp., Tank 3.	Steam pressure, No. 1.	Steam pressure, No. 6.	Ht. in Water Gauges. 1	2	3	6	Water to Boiler No. 6.	Temp.	Time.
		Deg.		Deg.									
4.40 A.M.	4,910	47	.....	65	124	115	5⅝	5½	....	7	390	78	5.40
4.50	.....	47	.....	64	122	116	5⅝	6½	....	6½	383	68	5.45
5.00	.....	47	.....	64	126	112	5½	6	....	5⅞	355	65	5.50
5.10	.....	48	.....	64	125	111	3⅝	4⅛	6⅜	5⅜	385	53	5.55
5.20	.....	48	.....	64	126	109	3⅜	2⅞	....	5⅜	384	48	6.00
5.30	.....	48	.....	64	131	111	3½	3⅜	....	4⅝	377	47	6.05
5.40	4,844	48	.....	64	127	108	2½	2⅜	....	3½	396	46	6.10
5.50	.....	48	1,034	64	121	111	3	3⅜	5⅛	5½	385	47	6.15
6.00	.....	47	.....	64	130	105	3½	3⅜	....	5½	355	47	6.20
6.10	4,949	47	.....	64	124	105	3	3½	....	5⅞	302	50	6.40
6.20	5,370	46	.....	64	121	105	4	3½	....	5½	387	52	6.50
6.30	.....	46	.....	64	125	109	5	5½	....	5⅜	390	50	6.55
6.40	245	46	910	64	123	111	6½	5½	4½	4⅜	386	48	6.58
6.50	760	46	.....	64	121	109	5⅜	5⅜	....	4⅜	379	48	7.00
7.00	3,747	46	.....	64	127	114	3½	2½	....	5	384	47	7.05
7.10	5,376	45.5	.....	64	122	101	3½	3⅜	....	5½	391	46	7.10
7.20	.....	45.5	.....	64	121	110	3	2½	3½	5½	392	48	7.20
7.30	4,739	45	.....	64	121	115	2⅞	2½	....	5⅜	383	57	8.10
7.40	.....	45	1,168	64	123	114	3	3½	....	5⅜	386	56	8.15
7.50	4,873	47	.....	64	119	113	3½	3½	....	4	371	52	8.20
8.00	4,942	48	.....	64	129	111	4⅜	3	....	3	391	48	8.25
8.10	.....	50	.....	62	124	110	4½	3½	....	2½	387	48	8.30
8.20	5,087	50	1,311	63	122	109	3⅝	3⅜	....	3	374	50	8.40
8.30	4,771	52	.....	62	124	105	3⅜	4½	....	2⅜	386	50	8.45
											381	49	8.50
											389	50	9.10
											391	50	9.25
											388	55	9.30
8.40	4,992	52	.....	62	122	114	1⅞	2½	....	3½	382	54	9.35
8.50	.....	54	.....	62	120	110	3⅜	2⅜	....	3½	384	51	9.40
9.00	.....	56	.....	62	124	110	2⅜	3⅜	....	3½	384	49	9.43
9.10	5,049	56	.....	62	125	117	2⅞	2½	....	3½	387	48	9.45
9.20	.....	58	1,160	63	124	118	2½	3⅜	?	2½	387	48	9.50
9.30	4,987	59	11,166	63	122	110	3	2½	....	2	379	49	9.55
9.40	.....	61	.....	63	122	110	1⅞	2⅜	..	3	385	49	10.00
9.50	4,732	62	.....	63	125	110	2	3	....	3½	389	49	10.05
10.00	.....	63	.....	64	124	110	2⅜	3	....	4½	390	50	10.30
10.10	5,140	65.5	1,143	64	125	109	4	3	....	4	392	54	10.35
10.20	4,946	66	13,452	64	121	112	4½	3⅜	....	3⅜	386	56	10.45
10.30	.....	67	.....	63	125	107	2½	2⅜	....	3½	387	53	10.50
10.40	5,388	68	.....	64	122	110	2⅜	2½	....	3	386	49	10.55
10.50	.....	68.5	.....	64	123	109	3	2½	....	3½	386	48	10.57
11.00	4,958	68.5	.....	64	122	111	3½	1⅜	....	4	381	48	11.00
11.10	.....	68.5	1,121	64	125	110	3½	2½	....	4⅜	381	48	11.05
11.20	4,948	69	15,694	64	122	112	3	4⅜	....	4	894	50	11.40
11.30	.....	69.5	.....	64	122	110	2⅜	2⅜	....	3½	386	56	11.44
11.40	4,907	69.5	.....	64	125	106	1⅜	1⅜	....	3⅜	385	59	11.46
11.50	.....	70	.....	64	125	109½	3⅜	3½	....	4½	381	50	11.48
12.00 M.	4,952	69	1,152	64	124	112	4½	3½	..	4½	386	48	11.50
12.10 P.M.	4,962	70	17,998	64	124	110	4½	3½	....	4½	379	48	11.55
12.20	.....	69.5	.....	64	126	110	4¼	5½	....	3½	391	48	12.00
12.30	.....	69	.....	64	125	110	1⅞	1⅜	...	3⅜	394	49	12.25
											382	55	12.30
											385	57	12.35
											390	53	12.40
											391	50	12.45
12.40	4,996	70	.....	65	121	112	2⅞	3⅜	....	3½	394	50	12.50
12.50	5,468	71	1,130	66	125	110	3⅜	3	...	4⅜	385	50	12.55
1.00	.....	72	.....	66	122	105	4½	4⅜	....	5⅜	381	50	1.00
1.10	5,096	73.5	.....	65	122	110	4	4⅜	....	5	392	54	1.30
1.20	.....	74	.....	65	123	114	4½	3⅜	....	3½	375	55	1.35
1.30	4,980	72	.....	65	124	110	3½	2½	.....	2⅜	383	50	1.40

TABLE VIII.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—FEED WATER AND OIL RECORD, ALSO GENERAL BOILER-ROOM RECORD.

Time.	Feed Water.		Oil Record.		Steam Gauges in Boiler Room, etc.								Time.
	Weight to Tank 3.	Temp., Tank 3.	Weight to Tank 3.	Temp., Tank 3.	Steam pressure, No. 1.	Steam pressure, No. 6.	Ht. in Water Gauges. 1	2	3	6	Water to Boiler No. 6.	Temp.	
		Deg.		Deg.									
1.40 P.M.	.....	73	1,147	66	125	105	2⅛	2⅛	....	3½	377	50	1.45
1.50	4,964	73	.....	66	121	110	3½	3½	....	3⅝	383	50	1.50
2.00	4,814	74	.....	66	120	113	5	3⅝	....	3⅝	388	49	2.00
2.10	4,918	74	.....	66	125	110	4⅜	3⅝	....	3	386	52	2.25
2.20	.....	74	.....	67	122	111	2	3½	....	2½	392	58	2.30
2.30	4,858	76	1,173	67	122	105	4½	4½	....	3	395	56	2.35
2.40	.....	78	.....	67	121	112	5⅜	5½	....	3	390	52	2.40
2.50	4,817	78	.....	67	125	111	5½	4½	....	3	396	50	2.45
3.00	4,763	80.5	.....	67	121	120	5	5½	1⅛	2⅞	390	50	2.50
3.10	.....	81.5	.....	67	121	111	4½	5½	....	2⅝	387	52	3.05
3.20	4,930	82	.....	68	124	104	5½	5½	....	5⅛	384	52	3.07
3.30	.....	83	1,213	68	125	106	4½	3	....	4½	373	50	3.09
3.40	5,059	83	.....	68	122	120	4⅛	4⅝	..	4	372	50	3.11
3.50	.....	84	.....	68	126	105	4¼	3	....	3½	372	49	3.12½
4.00	4,977	85.5	.....	68	123	105	4⅜	4⅜	...	3⅜	330	48	3.15
4.10	.....	88	.....	68	125	85	4	3½	....	3⅝	.....	.....	3.40
4.20	5,021	88	1,221	68	123	72	5⅜	5⅜	....	3½	380	56	3.50
4.30	5,045	88	.....	68	124	65	5⅜	4½	....	4½	384	58	3.55
4.40	.....	88	.....	68	123	125	5½	5½	....	3⅜	385	54	4.00
4.50	.....	88	.....	68	128	.....	3½	3⅜	....	3½	.....	.....	4.00
											391	52	4.02
											388	52	4.08
5.00	4,939	88	.....	68	125	0	3⅞	2⅜	....	4⅛	380	51	4.10
5.10	4,949	88	1,170	68	128	.....	1⅛	1	....	4⅜	391	50	4.12
5.20	.....	87.5	.....	68	125	.....	1½	2½	....	4½	384	50	4.20
5.30	5,030	88	.....	68	118	90	2	3	....	3⅜	384	50	4.25
5.40	.....	86.5	.....	68	120	94	4½	2	....	2⅜	384	52	4.35
5.50	4,919	86	.....	68	123	96	3	3	....	3½	.....	.....	4.36
6.00	5,085	86	.....	69	121	96	3⅜	2⅜	....	4⅜	386	54	4.42
6.10	.....	87	1,210	70	126	99	2⅜	1⅛	....	4½	389	52	4.45
6.20	4,950	87	.....	69	118	96	3⅜	2⅜	....	4	387	52	4.50
6.30	.....	87	.....	69	123	97	2⅜	2⅜	....	4⅜	375	52	4.55
6.40	4,942	87	.....	69	119	100	3½	2⅜	....	4⅜	384	50	5.00
6.50	4,943	87	.....	69	122	100	3⅜	3½	....	3⅞	379	55	5.45
7.00	.....	87	1,103	69	126	104	2½	2	....	3½	380	60	5.47
7.10	5,027	88	.....	69	121	102	3½	3½	....	3	379	58	5.50
7.20	.....	88	....	69	120	95	2⅝	3	....	4⅜	380	54	5.55
7.30	4,904	88	.....	69	122	100	1⅝	3	....	4⅞	377	50	5.58
7.40	4,978	88	.....	68	121	100	3⅛	5	....	6⅜	380	50	6.00
7.50	.....	86	1,231	68	123	103	5½	4½	....	6	379	50	6.05
8.00	4,989	85	.....	68	123	107	6½	5⅜	....	5	380	50	6.15
8.10	5,035	85	.....	68	123	111	6½	5½	....	4⅜	385	52	6.22
8.20	5,011	85	.....	68	123	110	6½	5⅜	...	4	382	52	6.27
8.30	5,069	85	1,086	68	123	109	6½	5½	....	3⅜	384	52	6.30
8.40	.....	84	.....	67	124	110	6	5½	....	5⅜	380	51	7.00
8.50	.....	84	.....	68	121	112	4⅞	3	....	4	377	58	7.05
9.00	.....	83 5	.....	67	123	110	3½	5	....	4	381	55	7.07
9.10	.....	83	.....	67	120	110	3⅜	3½	....	4⅛	386	53	7.10
											373	50	7.15
											380	50	7.20
9.20	4,995	82	.....	67	122	109	4⅜	3⅜	....	4½	380	51	7.23
9.30	5,062	82	.. ...	68	120	110	4½	3⅜	....	5	378	50	7.28
9.40	.....	82	1,167	68	122	105	4½	3½	....	4⅜	386	51	7.30
9.50	4,925	82	.....	67	124	107	2⅜	2⅜	....	5	373	50	7.33
10.00	5,073	84	.....	67	120	110	3⅜	3⅜	....	4⅜	379	54	8.17
10.10	189	85	.....	67	121	108	5½	5½	....	4	379	60	8.20
10.20	.....	84.5	1,100	67	123	111	6½	4½	....	4½	389	59	8.24
10.30	4,708	84	.....	67	124	100	4⅜	2½	....	5⅜	387	54	8.30
10.40	.....	85	.. ..	67	120	100	4	3⅜	....	5½	383	50	8.32
10.50	5,095	85	.....	67	125	99	3⅜	3½	..	4⅜	377	52	8.35
11.00	.....	83	.....	66	126	99	4⅜	3½	....	4	393	52	8.55
11.10	... ..	81	.....	67	122	100	5	4⅜	...	3⅜	383	54	9.00

TABLE VIII.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—FEED WATER AND OIL RECORD, ALSO GENERAL BOILER-ROOM RECORD.

Time.	Feed Water.		Oil Record.		Steam Gauges in Boiler Room, etc.								
	Weight to Tank 3.	Temp., Tank 3.	Weight to Tank 3.	Temp., Tank 3.	Steam pressure, No. 1.	Steam pressure, No. 6.	Ht. in Water Gauges. 1	2	3	6	Water to Boiler No. 6.	Temp.	Time.
		Deg.		Deg.									
11.20 P.M.	4.976	80.5	138	67	123	98	4	3½	....	3	382	56	9.15
11.30	.....	80	.....	67	120	90	3½	2⅜	....	4⅛	382	54	9.17
11.40	.....	81	.....	67	125	96	3⅝	2⅝	...	5⅜	383	54	9.20
11.50	.....	82	.....	67	124	100	4⅛	4⅛	....	6½	388	54	9.25
12.00	5,160	82	.....	67	123	99	4	4⅛	...	5¼	389	54	9.32
12.10 A.M.	.....	82	.....	67	126	90	4⅛	3⅛	..	4⅞	389	52	9.40
12.20	.....	81	.....	67	124	98	2¾	2⅛	....	4⅜	388	50	9.50
12.30	.....	82	.....	68	125	97	3⅛	4⅛	....	4	393	54	10.10
12.40	4,886	82	.. .	68	123	99	3	2⅜	....	4¼	376	56	10.12
12.50	.....	82	.....	68	120	105	4⅓	5	....	5⅛	381	55	10.15
1.00	.....	82	.....	70	123	110	6⅛	5½	....	4⅜	335	52	10.20
1.10	5,111	82	.....	70	123	106	5	5	....	4¼	386	50	10.25
1.20	.....	82	1,199	70	122	110	6⅜	5⅛	....	4	390	50	10.27
1.30	1,475	82	.....	70	123	107	6	4⅜	....	4⅛	392	53	11.20
1.40	.....	82	.....	70	123	110	6⅛	5⅛	....	4⅜	385	60	11.22
1.50	.....	82	.....	70	122	110	5⅛	5¼	....	4¼	290	58	11.24
2.00	.....	82	468	70	123	110	6¼	5¼	...	4⅜	...	.....	.....
											386	50	11.28
											385	48	11.30
											389	48	11.32
											381	48	11.35
											393	50	12 25
											379	55	12.27
											370	60	12.30
											382	50	12.32
											375	50	1.25
											388	48	1.28
											380	48	1.32
											389	50	1.50

TABLE IX

TEST NO. 2, ST. PAUL, MARCH 23, 1892—GAUGES AND REVOLUTION COUNTER, ENGINE NO. 2.

Time.	H. P. Steam.		I. P. Steam.		L.P.Steam.		Vacuum.		Counter.	No. Rev.
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.		
4.40	127	.....	26	....	−1	....	23.5	.....	886,211	....
4.50	123	.....	26	....	−1	....	23.5	.....	886,793	58.2
5.00	125	.....	26.5	....	0	....	24	.....	887,484	69.1
5.10	123	.....	26.5	....	1	....	23.5	.....	888,209	72.5
5 20	126	.....	29	....	1	....	23.5	.....	888,905	69.6
5.30	130	.....	28	....	−4	....	23.5	.....	889,611	70.6
5.40	125	.....	24	....	−7	....	23	.....	890,316	70.5
5.50	120	.....	26	....	0	....	24	.....	891,016	70.0
6.00	130	.....	30	....	−2	....	24	.....	891,725	70.9
6.10	125	.....	31	....	0	....	25	.....	892,123	49.8
6.20	120	.....	30	....	−1	....	24	.....	893,120	99.7
6.30	125	.....	30	....	−4	....	24	.....	898,823	70.3
6.40	125	.....	31	....	−2	....	24	.....	894,520	70.5
6.50	121	.....	30	....	3	....	24	.....	895,227	70.7
7.00	129	.....	31	....	−1	....	24	.....	895,927	70.0
7.10	120	.....	30	....	0	....	24	.....	896,622	69.5
7.20	120	.....	27	....	2	....	24	.....	897,329	69.7
7.30	120	.....	27	....	3	....	24	.....	898,010	68.1
7.40	120	.....	28	....	0	....	24	.....	898,713	70.3
7.50	120	.....	27	....	−1	....	24	.....	899,421	70.8
8.00	125	.....	28	....	3	....	24	.....	800,096	67.5
8.10	125	.....	27	....	0	....	24	.....	900,806	71.0
8.20	125	.....	27	....	0	....	25	.....	901,488	68.2
8.30	123	.....	29	....	0	....	24	.....	902,197	70.9
8.40	122	.....	28	....	1	....	24	.....	902,891	69.4
8.50	122	.....	28	....	0	....	24	.....	903,601	71.0
9.00	123	.....	27	....	2	....	24.5	.....	904,287	68.6
9.10	125	.....	29	....	−1	....	24.5	.....	904,999	71.2
9.20	127	.....	28	....	3	....	24	.....	905,680	68.1
9 30	123	.....	27	....	1	....	24	.....	906,377	69.7
9.40	121	.....	27	....	3	....	24	.....	907,074	69.7
9.50	124	.....	28	....	0	....	24.5	.....	907,777	70.3
10.00	123	.....	28	....	−1	....	24	.....	908,469	69.2
10.10	123	.....	27	....	1	....	24.5	.....	909,172	70.3
10.20	121	.....	28	....	2	....	24.5	.....	909,868	69.6
10.30	123	.....	28	....	3	....	24	.....	910,564	69.6
10.40	121	.....	27	....	1	....	24.5	.....	911,264	70.0
10.50	122	.....	27	....	2	....	24	.....	911,952	68.8
11.00	122	.....	27	....	0	....	24	.....	912,652	70.0
11.10	124	.....	28	....	2	....	24	.....	913,364	71.2
11.20	123	.....	27	....	1	....	24.5	.....	914,954	59.0
11.30	121	.....	27	....	1	....	24	.....	914,746	79.2
11.40	125	.....	28	....	1	....	24	.....	915,451	70.5
11.50	120	.....	26	....	3	....	24	.....	916,144	69.3
12.00	125	.....	28	....	1	....	24.5	.....	916,895	75.1
12.10	125	.....	28	....	−2	....	24.5	.....	917,539	64.4
12.20	118	.....	26	....	3	....	24	.....	918,243	70.4
12.30	125	.....	28	....	1	....	24	.....	918,927	68.4
12.40	120	.....	25	....	−1	....	24	.....	919 617	69.0
12.50	125	.....	27	....	−1	....	24.5	.....	920,317	70.0
1.00	120	.....	26	....	0	....	24.5	.....	921,924	60.7

TABLE IX.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—GAUGES AND REVOLUTION COUNTER, ENGINE NO. 2.

Time.	H. P. Steam.		I. P. Steam.		L.P.Steam.		Vacuum.		Counter.	No. Rev.
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.		
1.10	122	.....	25	...	−1	....	24	.....	921,710	78.6
1.20	124	.....	26	....	1	....	24	.....	922,411	70.1
1.30	124	.....	26	....	0	....	24	.....	923,108	69.7
1.40	125	.....	27	....	0	....	24	.....	923,812	70.4
1.50	125	.....	26	....	0	....	24.5	.....	924,513	70.1
2.00	120	.....	25	....	1	....	24	.....	925,205	69.2
2.10	125	.....	26	....	−1	....	24	.....	925,909	70.4
2.20	122	.....	25	....	1	...	24	.....	926,604	69.5
2.30	122	.....	24	....	−2	..	24	.....	927,291	68.7
2.40	120	.....	25	....	1	....	24	.....	927,987	69.6
2.50	122	.....	26	...	0	....	24	.....	928,702	71.5
3.00	120	.....	26	....	0	....	24	.....	929,364	66.2
3.10	121	.....	26	....	0	....	24.5	.....	930,097	73.3
3.20	124	.....	27	....	−3	....	24.5	.....	930,788	69.1
3.30	125	.....	28	....	0	....	24.5	.....	931,456	66.8
3.40	118	.....	25	....	2	....	24	.....	932,171	71.5
3.50	125	.....	28	....	0	....	24.5	.....	932,859	68.8
4.00	119	.....	28	....	1	....	25	.....	933,566	70.7
4.10	123	.....	28	....	3	....	24.5	.....	934,267	70.1
4.20	123	.....	28	....	2	....	24.5	.....	934,938	67.1
4.30	123	.....	28	....	2	....	24.5	.....	935,657	71.9
4.40	121	.....	25	....	0	....	24	.....	936,339	68.2
4.50	127	.....	27	....	−1	....	23.5	.....	937,059	72.0
5.00	126	.....	28	....	2	....	24	.....	937,747	68.8
5.10	127	.....	29.5	....	3	....	24	.....	938,450	70.3
5.20	124	.....	30	....	1	....	23.5	.....	939,151	70.1
5.30	118	.....	29	....	0	....	24	.....	939,848	69.7
5.40	118	.....	28	....	2	....	24	.....	940,524	67.6
5.50	123	.. ..	30	....	3	....	24.5	.....	941,237	71.3
6.00	120	.....	28	...	0	....	24	.....	941,950	71.3
6.10	124	.....	30	....	2	....	24	.....	942,614	66.4
6.20	118	.....	28	....	0	....	24	.....	943,288	67.4
6.30	122	.....	28	....	−4	....	24	.....	944,020	73.8
6.40	118	.....	26	....	0	....	23.5	.....	944,712	69.2
6.50	125	.....	28	....	−3	....	24	.....	945,393	68.1
7.00	130	.....	30	....	−7	....	24	.....	946,083	69.0
7.10	121	.....	26	....	0	....	24	.....	946,788	70.5
7.20	120	.....	26	..	0	...	24	.....	947,198	41.0
7.30	125	.....	27	...	−3	....	24	.....	948,181	98.3
7.40	125	.....	27	....	1	....	24	.....	948,882	70.1
7.50	123	.....	26	....	−1	...	24	.....	949,580	69.8
8.00	122	.....	25	...	−7	....	24	.....	950,304	72.4
8.10	123	.....	27	....	0	....	24	.....	950,989	68.5
8.20	121	.....	28	....	1	..	24.5	.....	951,682	69.3
8.30	121	.....	24	....	0	..	24	.....	952,364	68.2
8.40	122	.....	26	....	−2	....	24	.....	953,078	71.4
8.50	122	.....	27	....	−1	...	24	.....	953,800	72.2
9.00	122	.....	30	....	−1	....	24	.....	954,493	69.3
9 10	120	.....	28	....	−1	....	24	.....	955,193	70.0
9.20	120	.....	28	....	0	....	24	.....	955,890	70.5
9.30	120	.....	27	....	0	....	24	.....	956,596	69.8
9.40	123	.....	29	....	1	....	24	.....	957,298	70.2
9 50	123	.....	27	....	−3	....	24	.....	957,986	68.8
10.00	120	.....	26	....	−1	....	24	.....	958,696	71.0
10.10	120	.....	29	....	4	....	24	.....	959,404	70.8
10.20	123	.....	27	....	0	....	24	.....	960,120	71.6

TABLE X.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—GAUGES AND REVOLUTION COUNTER, ENGINE NO. 3.

Time.	H. P. Steam.		I. P. Steam.		L. P. Steam.		Vacuum.		Counter.	No. Rev.
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.		
5.30	130	.....	—6	....	1	....	24.	.....	313,907	.....
5.40	127	.....	30	....	—3	....	25.	.....	314,417	51.0
5 50	123	.....	26	....	1	....	24.5	.....	315,108	69.1
6.00	130	.....	29	....	0	....	25.	.....	315,826	71.8
6.10	125	.....	27	....	—3	....	25.	.....	316,532	70.6
6.20	134	.....	27	....	1	....	24.	.....	317,246	71.4
6.30	125	.....	32	....	—2	....	25.	.....	317,954	70.8
6.40	125	.....	31	....	0	....	25.	.....	318,660	70.6
6.50	120	.....	29	....	2	....	25.	.....	319,372	71.2
7.00	127	.....	31	.	1	....	24.5	.....	320,081	70.9
7.10	123	.....	30	....	1	....	24.	.....	320,782	70.1
7.20	130	.....	30	....	2	....	24.5	.....	321,492	71.0
7.30	120	.....	30	....	2	....	24.5	.....	322,206	71.4
7.40	124	.....	32	....	2	....	24.	.....	322,908	70.2
7.50	120	.....	30	....	1	....	24.	.....	323,633	72.5
8.00	124	.....	31	....	3	....	24.	.....	324,316	68.3
8.10	125	.....	31	....	2	....	24.	.....	325,040	72.4
8.20	125	.....	30	....	1	....	24.	.....	325,708	66.8
8.30	125	.....	31	....	1	....	25.	.....	326,450	74.2
8.40	23	.....	31	....	0	...	24.5	.....	327,161	71.1
8.50	123	.....	29	....	1	....	24.5	.....	327,876	71.5
9.00	125	.....	30	....	1	....	24.5	.....	328,593	71.7
9.10	126	.....	31	....	—1	....	24.5	.....	329,288	69.5
9.20	125	.....	30	....	1	....	24.5	.....	329,992	70.4
9.30	125	.....	31	....	1	....	24.5	.....	330,703	71.1
9.40	122	.....	30	....	1	....	24.5	.....	331,430	72.7
9.50	125	.....	31	....	1	....	24.5	.....	332.124	69.4
10.00	125	.....	31	....	0	....	24.5	.....	332,824	70.0
10.10	125	.....	31	...	1	....	24.5	.....	333,542	71.8
10.20	122	.....	30	....	0	....	24.5	.....	334,252	71.0
10.30	127	.....	30	...	—1	....	24.5	.....	334,962	71.0
10.40	124	.....	31	....	1	...	24.5	.....	335,652	69.0
10.50	124	.....	31	....	1	....	24.5	.....	336.371	71.9
11.00	123	.....	30	....	0	....	24.5	.....	337,090	71.9
11.10	129	.....	31	....	0	....	24.5	.....	337,810	72.0
11.20	123	.....	31	....	1	....	24.5	.....	338,508	69.8
11.30	125	.....	31	....	0	....	24.5	.....	339,212	70.4
11.40	128	.....	32	....	—1	....	24.5	.....	339,933	72 1
11.50	120	.....	30	....	0	....	24.5	.....	340,636	70.3
12.00	126	.....	31	....	1	....	24.5	.....	341,347	71.1
12.10	128	.....	30	....	—1	..	24.5	.....	342,062	71.5
12.20	123	.....	30	....	0	....	24.5	.....	342,783	72.1
12.30	125	.....	31	....	0	....	24.5	.....	343,465	68.2
12.40	122	.....	29	...	—1	....	24.5	.....	344,148	68.3
12.50	125	.....	30	....	2	....	24.5	.....	344,862	71.4
1.00	124	.....	31	....	0	....	24.5	.....	345,602	74.0
1.10	123	.....	31	....	1	....	24.5	.....	346,286	68.4
1.20	125	.....	31	....	—1	....	25.	.....	347,005	71.9
1.30	125	.....	31	....	0	..	25.0	.....	347,712	70.7

TABLE X.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—GAUGES AND REVOLUTION COUNTER, ENGINE NO. 3.

Time.	H. P. Steam.		I. P. Steam.		L. P. Steam.		Vacuum.		Counter.	No. Rev.
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.		
1.40	125		31		0		24.5		348,433	72.1
1.50	120		30		0		24.5		349,143	71.0
2.00	120		30		0		24.5		349,844	70.1
2.10	125		32		0		24.5		350,553	70.9
2.20	124		30		0		24.5		351,264	71.1
2.30	123		30		−1		24.5		351,968	70.4
2.40	120		30		0		24.5		352,660	69.2
2.50	123		30		0		24.5		353,396	73.6
3.00	120		30		0		24.5		354,094	69.8
3.10	120		31		0		24.5		354,818	72.4
3.20	125		31		0		24.5		355,507	68.9
3.30	126		31		0		24.5		356,200	69.3
3.40	119		29		1		24.5		356,909	70.9
3.50	125		31		0		24.5		357,607	69.8
4.00	123		29		−3		24.5		358,331	72.4
4.10	125		30		0		24.5		359,053	72.2
4.20	125		30		0		24.		359,727	67.4
4.30	125		31		0		24.5		360,452	72.5
4.40	123		30		0		24.5		361,145	69.3
4.50	127		32		0		24.		361,900	75.5
5.00	125		31		0		24.		362,626	72.6
5.10	126		32.5		0		24.5		363,308	68.2
5.20	126		32		0		24.		364,027	71.9
5.30	118		29		0		24.5		364,714	68.7
5.40	118		29		0		24.5		365,401	70.7
5.50	125		31		0		24.5		366,141	74.0
6 00	120		30		0		24.5		366,866	72.5
6.10	127		31		1		24.		367,544	67.8
6.20	120		29		2		24.5		368,210	66.6
6.30	123		30		1		24.5		368,942	73.2
6.40	120		27		0		24.5		369,658	71.6
6.50	125		30		−3		24.5		370,353	69.5
7.00	127		31		−6		24.5		371,042	68.9
7.10	120		29		0		24.5		371,764	72.2
7.20	118		27		3		24.5		372,491	72.7
7.30	124		30		−1		24.5		373,188	69.7
7.40	124		30		0		24.5		373,878	69.0
7.50	122		29		1		24.5		374,594	71.6
8.00	124		29		0		24.5		375,174	58.0
8.10	124		30		0		24.5		375,794	62.0
8.20	120		30		1		24.5		376,487	69.3
8.30	124		31		5		24.5		377,181	69.4
8.40	121		30		3		24.5		377,886	70.5
8.50	120		29		−3		24.5		378,614	72.8
9.00	125		30		−1		24.5		379,350	73.6
9.10	123		30		−3		24.5		380,031	68.1
9.20	123		30		0		24 5		380,741	71.0
9.30	120		30		1		24.5		381,446	70.5
9.40	123		30		0		24.5		382,161	71.5

TABLE X.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—GAUGES AND REVOLUTION COUNTER, ENGINE NO. 3.

Time.	H. P. Steam.		I. P. Steam.		L. P. Steam.		Vacuum.		Counter.	No. Rev.
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.		
9.50	125	.....	31	....	0	....	24.5	.....	382,831	67.0
10.00	120	.....	29	....	1	....	24.5	.....	383,556	72.5
10.10	120	.....	30	....	1	....	24.5	.....	384,270	72.4
10.20	127	.....	31	....	−3	....	24.5	.....	384,971	70.1
10.30	126	.....	29	....	0	....	24.5	.....	385,645	67.4
10.40	123	.....	27	....	0	....	24.5	.....	386,348	70.3
10.50	125	.....	31	....	−5	...	24.5	.....	387,060	71.2
11.00	127	.....	32	....	−1	....	24.5	.....	387,778	71.8
11.10	120	.....	29	....	−3	....	24.5	.....	388,467	68.9
11.20	123	.....	29	....	−2	....	24.5	.....	389,168	70.1
11 30	123	.....	29	....	−7	....	25.	.....	389,883	71.5
11.40	125	.....	31	....	−2	....	25.	.....	390,583	70.0
11.50	122	.....	30	....	1	....	25.	.....	391,303	72.0
12.00	121	.....	30	....	−4	....	25.	.....	392,021	71.8
12.10	127	.....	31	....	−3	....	25.	.....	392,723	70.2
12.20	125	.....	32	....	0	....	25.	.....	393,419	69.6
12.30	124	.....	31	....	0	....	25.	.....	394,137	71.8
12.40	125	.....	31	....	−4	....	24.5	.....	394,847	71.0
12.50	120	.....	31	....	0	....	24.5	.....	395,560	71.3
1.00	120	.....	31	....	0	....	24.5	.....	396,260	70.0
1.10	121	.....	31	....	0	....	24.5	.....	397,001	74.1
1.20	122	.....	31	....	0	....	24.5	.....	397,702	70.1
1.30	123	.....	30	....	−1	....	24.5	.....	398,416	71.4
1.40	123	.....	29	....	−2	....	25.	.....	399,133	71.7
1.50	122	.....	31	....	0	....	25.	.....	399,847	71.4
2.00	123	.....	31	....	0	....	25.	.....	400,571	72.4
										69.4

TABLE XI.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—TEMPERATURES IN CONDENSERS.

Time.	Temp. of Injection Water.	Temp. of Hot Well 2.	Temp. of Hot Well 3.	Remarks.
	Deg. Fahr.	Deg. Fahr.	Deg. Fahr.	
4.40	45	68	60	
4.50	40	68	62	
5.00	44	68	64	
5.10	41	68	66	
5.20	46	67.1	63	
5.30	46	66.2	46	
5.40	43	67.1	65	
5.50	42	67.1	68	
6.00	42	68	72	
6.10	42	69.8	70	
6.20	41	69.8	80	
6.30	44	71.6	80	
6.40	40.5	73.4	81	
6.50	41	77	82	
7.00	45	77	90	
7.10	46	78.8	92	
7.20	42	82.4	94	
7.30	41	86	94	
7.40	41	86	100	
7.50	40.5	87.8	100	
8.00	41	87.8	104	
8.10	40	87.8	98	
8.20	41	87.8	98	
8.30	41	87.8	94	
8.40	41	87.8	94	
8.50	41	87.8	90	
9.00	41	84.2	98	
9.10	41	86	96	
9.20	41	87.8	98	
9.30	41	87.8	93	Began here taking temperature of injection water every half-hour.
9.40	.....	86 9	94	
9.50	.....	87.8	94	
10.00	40	87.8	93	
10.10	.....	87.8	93	
10.20	.....	88.7	94	
10.30	41	89.6	95	
10.40	.....	88.7	98	
10.50	.....	87.8	95	
11.00	41	86	94	
11.10	.....	89.6	100	
11.20	.....	87.8	100	
11.30	41	89 6	102	
11.40	.....	89.6	98	
11.50	.....	88.7	96	
12.00	41	87.8	96	
12.10	.....	88.7	94	
12.20	.....	89.6	100	
12.30	42	91.4	100	
12.40	.....	89.6	94	
12.50	.....	89.6	99	
1.00	41	89.6	95	
1.10	.....	87.8	104	

TABLE XI.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—TEMPERATURES IN CONDENSERS.

Time.	Temp. of Injection Water.	Temp. of Hot Well 2.	Temp. of Hot Well 3.	Remarks.
	Deg. Fahr.	Deg. Fahr.	Deg. Fahr.	
1.20	.....	88.7	90	
1.30	41	87.8	94	
1.40	.....	89.6	98	
1.50	.....	89.6	96	
2.00	40	91.4	93	
2.10	.....	89.6	100	
2.20	.....	89.6	100	
2.30	43	87.8	98	
2.40	.....	88.7	99	
2.50	.....	86	99	
3.00	41	87.8	98	
3.10	.....	86.9	98	
3.20	.....	87.8	98	
3.30	41.9	89.6	98	At this point exchanged with Mr. Couper a Fahrenheit thermometer for a centigrade for temperature of injection water. (Brass case.)
3.40	.....	87.8	98	
3.50	.....	89.6	99	
4.00	.....	82.4	99	
4.10	42.8	86	98	
4.20	.....	87.8	100	
4.30	41.9	89.6	102	
4.40	.....	89.6	104	
4.50	.....	92.3	109	
5.00	40.1	91.4	100	
5.10	.....	87.8	99	
5.20	.....	86	100	
5.30	41	86	100	
5.40	.....	86	100	
5.50	.....	86	100	
6.00	40.1	86	102	
6.10	.....	86.9	104	
6.20	.....	87.8	98	
6.30	39.65	87.8	100	
6.40	.....	87.8	90	
6.50	.....	87.8	86	
7.00	41	86	86	
7.10	.....	85.28	86	
7.20	.....	85.1	86	
7.30	40.55	86	84	
7.40	.....	84.2	88	
7.50	.....	77	90	
8.00	39.2	77	92	
8.10	.....	77	90	
8.20	.....	76.1	80	
8.30	40.64	75.2	90	
8.40	.....	77	90	
8.50	.....	75.2	86	
9.00	41	75.2	88	
9.10	.....	75.2	88	
9.20	.....	75.2	86	
9.30	40.1	75.2	88	
9.40	.....	73.4	84	
9.50	.....	73.4	86	

TABLE XI.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—TEMPERATURES IN CONDENSERS.

Time.	Temp. of Injection Water.	Temp. of Hot Well 2.	Temp. of Hot Well 3.	Remarks.
	Deg. Fahr.	Deg. Fahr.	Deg. Fahr.	
10.00	40.46	73.4	88	
10.10	.....	73.4	90	
10.20	.....	73.4	88	
10.30	40.28	73.4	98	
10.40	.....	73.4	92	
10.50	.....	73.4	92	
11.00	41.36	73.4	86	
11.10	.....	73.4	90	
11.20	.....	73.4	90	
11.30	39.56	73.4	82	
11.40	.....	73.4	78	
11.50	.....	73.4	76	
12.00	39.56	73.4	72	
12.10	.....	73.4	71	
12.20	.....	73.4	68	
12.30	40.64	73.4	70	
12.40	.....	73.4	68	
12.50	.....	73.4	69	
1.00	39.2	73.4	66	
1.10	.....	73.4	66	
1.20	.....	73.4	68	
1.30	40.1	73.4	66	
1.40	.....	73.4	64	
1.50	.....	73.4	64	
2.00	39.65	73.4	64	
	41.3			

TABLE XII.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—WATER FROM JACKETS, ETC., ENGINE NO. 2.

Time.	L. PRESS. Barrel 1, full.	L. PRESS. Barrel 1, empty.	L. PRESS. Barrel 2, full.	L. PRESS. Barrel 2, empty.	Discharge.	Remarks.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
6.01	439⅝	87½	.....	.....	352	
7.05	.....	.....	407	83½	323½	
8.00	438½	87½	.....	.....	351	
8.50	.....	.....	402¼	83¼	319	
9.45	458	87½	.....	.....	370½	
10.35	.....	.....	425	89¾	335½	Extra weight on barrel is cover.
11.30	457	96	.....	.....	361	
12.25	.....	.....	462½	90¼	372	
1.30	517	96½	.....	.....	420½	Barrel full.
2.20	.....	.....	441	91	350	
3.15	464	97	.....	.....	367	
4.00	.....	.....	432	92	340	
5.00	462	97½	.....	.....	364½	
5.45	.....	.....	423	94	329	
6.35	446½	98	.....	.....	348½	Temp., 212° F.
7.25	.....	.....	476	93	383	
8.20	456	98	.....	.....	358	Temp., 210½° F.
9.27	.....	.....	464¼	93½	370¾	
10.20	351	99½	.....	.....	251½	Shut down No. 2.
Began 4.40 A.M.	H. AND I. PRESS.		H. AND I. PRESS.			
5.37	430	81½	.....	.....	348½	
6.20	.....	.....	393	73	320	
6.47	339¼	81	.....	.....	258¼	
7.18	.....	.....	378	74½	293¾	Some water in barrel.
7.45	387¾	81	.....	.....	306¾	
8.07	.....	.....	363½	73¼	290¼	
8.30	366¼	81¼	.....	.....	285	
8.57	.....	.....	376¼	73¼	303	
9.35	444½	81¼	.....	.....	363¼	Exchange valves for convenience.
9.50	.....	.....	343½	73¼	270¼	
10.20	429½	81¼	.....	.....	348¼	
10.41	.....	.....	338½	73¼	265¼	
11.10	440	92½	.....	.....	347½	Extra weights on barrels are covers.
11.32	.....	.....	345¼	81⅛	263⅜	
12.00	421½	93	.....	.....	328½	
12.25	.....	.....	466	81⅛	384⅛	
12.52	437½	93	.....	.....	344½	
1.20	.....	.....	430	82	348	
1.50	437½	92.5	.....	.....	345	
2.10	.....	.....	345.5	82½	263	
2.40	441½	93	.....	.....	348½	Lid is saturated with water.
3.05	.....	.....	400½	83½	317	
3.35	451½	95	.....	.....	356½	
4.00	.....	.....	391	83½	307½	
4.30	431½	95¼	.....	.....	336¼	
4.55	.....	.....	396	84.5	311.5	
5.22	441	96.5	.....	.....	344.5	
5.45	.....	.....	413	86	327	
6.10	445	96.5	.....	.....	348.5	
6.40	.....	.....	430.5	86	344.5	Temp., 212° F.
7.00	410	97.75	.....	.....	312.25	
7.30	.....	.....	427.5	86	341.5	
7.45	411.5	98	.....	.....	313.5	Temp., 212° F
8.30	.....	.....	422.5	86	336.5	
9.10	432.5	98.25	.....	.....	334.25	
9.50	.....	.....	419	86.5	332.5	Temp. of room, 71° F.
0.20	327	98.5.	.....	.....	228.5	
					18,571	Av. temp., 211. 6°.

TABLE XIII.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—WATER FROM JACKETS, ETC., ENGINE NO. 3.

Time.	L. PRESSURE.		L. PRESSURE.		Discharged.	Remarks.
	Barrel 1, full.	Barrel 2, empty.	Barrel 2, full.	Barrel 2. empty.		
Started 5.34						
6.27	379.	79.5				
7.10			384.	95.	300.	
8.00	452.25	79.			373.25	
8.52			460.	93.	367.	
9.40	428.	80.25			347.75	
10.30			472.	95.	377.	
11.25	478.5	87.			391.5	
12.15			477.	102.	375.	
1.10	486.	87.25			398.75	
2.02			492.	103.5	388.5	
2.50	463.	89.5			373.5	
3.32			422.5	102.5	320.0	
4.25	479.5	88.5			391.0	
5.15			487.5	104.5	388.	
6.02	469.	90.			379.	
6.45			440.	105.5	334.5	Temp., 212° F.
7.30	472.	90.5			381.5	
8.10			442.	105.5	336.5	Temp., 211° F.
8.45	456.	91.			365.	Temp., 210° F.
9.27			455.	106.5	348.5	
10.10	440.5	91.			349.5	
10.50			464.	107.	357.	
11.30	464.	91.			373.	
12.12			455.	107.	348.	
1.10	433.	91.			342.	
2.00			349.5	107.	342.5	
Started 5.34	H. AND I. PRESSURE.		H. AND I. PRESSURE.			
6.15	387.0	87.5			299.5	
6.50			408.5	76.5	345.0	
7.30	455.0	88.			367.0	
8.00			425.5	76.5	364.	
8.37	454.0	88.			366.0	
9.15			454.5	77.	394.5	
9.55	460.5	91.			369.5	Corr. used.
10.35			485.5	84.5	419.5	
11.10	450.5	97.			353.0	Such water included in each bbl. for its respective time.
11.55			505.0	85.0	420.0	
12.30	466.0	96.5			369.5	
1.10			476.0	85.0	391.0	
1.40	451.5	97.			354.5	
2.25			501.5	87.0	414.5	
2.55	437.0	97.			340.0	
3.32			486.5	88.5	398.0	
4.06	447.5	101.			346.5	
4.43			477.0	88.0	389.0	
5.15	462.0	99.			363.0	
5.50			478.	86 5	391.5	
6.20	452.5	101.			351.5	
6.55			480.	88.5	391.5	Temp., 212° F.
7.23	465.	100.			365.	
7.55			435.	89.5	345.5	Temp., 209½° F.
8.20	467.	103.5			363.5	Temp., 211½° F.
8.45			454.	90.	364.	Temp., 209½° F.
9.13	439.	104.			338.	
9.40			472.5	90.	382.5	
10.15	472.5	104.			368.5	
10.40			467.5	90.5	377.	
11.05	463.5	102.5			361.	
11.30			441.5	88.	358.5	
12 05	489.	93.			396.	Temp. of room, 70½°F.
12.40			421.	91.	330.	Weights without cover.
1.30	476.	93.			383.	
2.00			281.5	91.	190.5	
					22,338.25	Average temp., 210.8°.

TABLE XIV.

Test No. 2, St. Paul, March 23, 1892—Water for Auxiliary Boiler.

Time.	Barrel full.	Barrel empty.	Sent to Boiler.	Temperature.	Remarks.	Time.	Barrel full.	Barrel empty.	Sent to Boiler.	Temperature.	Remarks.
Start 4.40 A.M.				Deg. F.	Lower barrel full.					Deg. F.	
5.40 A.M.	502	112	390	78		1.40 P.M.	508	125	383	50	
5.45	502	119	383	68		1.45	506	129	377	50	
5.50	491	136	355	65		1.50	506	123	383	50	
5.55	500	115	385	53		2.00	509	121	388	49	
6.00	498	114	384	48		2.25	506	120	386	52	
6.05	502	125	377	47		2.30	515	123	392	58	
6.10	507	111	396	46		2.35	515	120	395	56	
6.15	501	116	385	47		2.40	511	121	390	52	
6.20	502	147	355	47	151-147	2.45	511	120	391	50	
						2.50	509	119	390	50	
Start 2d.						3.05	513	126	387	52	
6.40	495	193	302	50	Lower b. 2′ from top.	3.07	511	127	384	52	
						3.09	505	132	373	50	
6.50	493	106	387	52		3.11	502	130	372	50	
6.55	495	105	390	50		3.12½	504	132	372	49	
6.58	495	109	386	48		3.15	507	177	330	48	
7.00	490	111	379	48		3.40	Safety valve popped.				1 minute.
7.05	495	111	384	47		3.50	500	120	380	56	
7.10	496	105	391	46		3.55	507	123	384	58	
7.20	510	118	392	48		4.00	508	123	385	54	
8.10	502	119	383	57		4.00	Both safety valves twice.				1 minute.
8.15	505	119	386	56		4.02	511	120	391	52	
8.20	502	131	371	52		4.08	516	128	388	50	
8.25	509	118	391	48		4.10	505	125	388	51	
8.30	505	118	387	48		4.12	511	120	391	50	
8.40	504	130	374	50		4.20	508	124	384	50	
8.45	506	120	386	50		4.25	506	122	384	50	
8.50	503	122	381	49		4.35	507	123	384	52	
9.10	506	117	389	50		4.36	Safety valve popped.				¼ minute.
9.25	512	121	391	50		4.42	505	119	386	54	
9.30	506	118	388	55		4.45	509	120	387	52	
9.35	506	124	382	54		4.50	510	123	387	52	
9.40	506	122	384	51		4.55	507	132	375	52	
9.43	510	126	384	49		5.00	508	124	384	50	
9.45	507	120	387	48		5.45	505	126	379	55	
9.50	505	118	387	48		5.47	505	125	380	60	
9.55	506	127	379	49		5.50	505	120	379	58	
10.00	503	118	385	49		5.55	505	125	380	54	
10.05	509	120	389	49		5.58	502	125	377	50	
10.30	512	122	390	50		6.00	506	126	380	50	
10.35	509	117	392	54		6.05	506	127	379	50	
10.45	508	122	386	56		6.15	511	131	380	50	
10.50	508	121	387	53		6.22	508	123	385	52	
10.55	509	123	386	49		6.27	509	127	382	53	
10.57	508	122	386	48		6.30	509	125	384	52	
11.00	506	125	381	48		7.00	504	124	380	51	
11.05	508	127	381	48		7.05	504	127	377	58	
11.40	515	121	394	50		7.07	506	125	381	55	
11.44	508	122	386	56		7.10	506	120	386	53	
11.46	507	122	385	59		7.15	502	129	373	50	
11.48	508	127	381	50		7.20	504	124	380	50	
11.50	509	123	386	48		7.23	507	127	380	51	
11.55	509	130	379	48		7.28	506	128	378	50	
12.00 M.	512	121	391	48		7.30	510	124	386	51	
12.25 P.M.	512	118	394	49		7.33	504	131	373	50	
12.30	510	128	382	55		8.17	508	129	379	54	
12.35	510	125	385	57		8.20	507	128	379	60	
12.40	510	120	390	53		8.24	507	118	389	59	
12.42	510	119	391	50		8.30	511	124	387	54	
12.50	513	119	394	50		8.32	506	123	383	50	
12.55	507	122	385	50		8.35	507	130	377	52	
1.00	504	123	381	50		8.55	511	118	393	52	
1.30	514	122	392	54		9.00	507	124	383	54	
1.35	501	126	375	55		9.15	507	125	382	56	

TABLE XIV.—*Continued.*

TEST NO. 2. ST. PAUL, MARCH 23, 1892—WATER FOR AUXILIARY BOILER.

Time.	Barrel full.	Barrel empty.	Sent to Boiler.	Temperature.	Remarks.	Time.	Barrel full.	Barrel empty.	Sent to Boiler	Temperature.	Remarks.
				Deg.						Deg.	
9.17 P.M.	506	124	382	54		11.24 P.M.	508	118	390	58	
9.20	506	123	383	54		11.28	509	123	386	50	
9.25	512	124	388	54		11.30	508	123	385	48	
9.32	507	118	389	54		11.32	512	123	389	48	
9.40	513	124	389	52		11.35	509	128	381	48	
9.50	507	119	388	50		12.25 A.M.	515	122	393	50	
10.10	512	119	393	54		12.27	506	127	379	55	
10.12	503	127	376	56		12.30	500	130	370	60	
10.15	506	125	381	55		12.32	507	125	382	50	
					Water in	1.25	504	129	375	50	
10.20	510	175	335	52	bbl. 2′	1.28	507	119	388	48	
					from top.	1.32	507	127	380	48	
10.25	515	129	386	50		1.50	511	122	389	50	
10.27	512	122	390	50							
11.20	510	118	392	53		Total water..... ..... 53,615 lbs.					
11.22	511	126	385	60		Average temperature.....52.6°					

TABLE XV.

Test No. 2, St. Paul, March 23, 1892—Temperatures, etc.

Time.	Pyrometer No. 1.	Pyrometer No. 2.	Draught Gauge.	Temperature in boiler room.	Barometer.	Feed-water temperature near economizer.	Feed water near boiler.
5.00 P.M.	320	365	$\frac{5}{8}$	86	28.89	132	210
4.00 A.M.	330	320	$\frac{9}{16}$	74	28.98	82	122
4.40	290	315	$\frac{9}{16}$	70	28.99	110	132
4.50	260	310	$\frac{1}{2}$	70	28.99	110	175
5.00	260	320	$\frac{1}{2}$	68	28.99	107	160
5.10	320	280	$\frac{7}{16}$	69	29.01	110	145
5.20	280	285	$\frac{1}{2}$	68	29.01	115	145
5.30	180	325	$\frac{1}{2}$	72	29.01	115	155
5.40	270	315	$\frac{1}{2}$	70	29.02	115	160
5.50	250	320	$\frac{5}{8}$	64	29.02	135	170
6.00	320	325	$\frac{1}{2}$	68	29.03	125	180
6.10	220	325	$\frac{1}{2}$	71	29.03	110	205
6.20	270	325	$\frac{1}{2}$	70	29.03	105	145
6.30	290	335	$\frac{5}{8}$	68	29.06	88	125
6.40	310	340	$\frac{5}{8}$	68	29.06	85	135
6.50	390	320	$\frac{1}{2}$	66	29.07	90	130
7.00	330	330	$\frac{1}{2}$	70	29.07	90	170
7.10	320	340	$\frac{5}{8}$	70	29.08	110	160
7.20	345	325	$\frac{9}{16}$	68	29.08	120	180
7.30	325	340	$\frac{5}{8}$	70	29.09	105	145
7.40	350	340	$\frac{5}{8}$	70	29.09	95	140
7.50	340	335	$\frac{5}{8}$	69	29.09	95	145
8.00	440	315	$\frac{1}{2}$	70	29.10	95	140
8.10	300	340	$\frac{5}{8}$	.....	29.10	95	135
8.20	345	335	$\frac{3}{4}$	.....	29.10	95	160
8.30	335	340	$\frac{1}{2}$	.....	29.10	100	165
8.40	320	340	$\frac{9}{16}$	.....	29.10	100	187
8.50	335	340	$\frac{1}{2}$	.....	29.10	110	145
9.00	340	340	$\frac{5}{8}$	.....	29.10	100	160
9.10	355	330	$\frac{9}{16}$	.....	29.10	105	150
9.20	340	340	$\frac{5}{8}$	.....	29.10	105	160
9.30	330	340	$\frac{5}{8}$	.....	29.10	105	160
9.40	330	335	$\frac{5}{8}$	.....	29.10	105	175
9.50	335	345	$\frac{5}{8}$	.....	29.10	110	152
10.00	330	340	$\frac{5}{8}$	.....	29.10	105	160
10.10	330	340	$\frac{5}{8}$	.....	29.10	105	155
10.20	330	340	$\frac{9}{16}$	74	29.10	105	135
10.30	330	340	$\frac{9}{16}$	.....	29.10	110	162
10.40	330	340	$\frac{9}{16}$	72	29.10	115	140
10.50	340	340	$\frac{1}{2}$	....	29.10	120	185
11.00	360	335	$\frac{1}{2}$	.....	29.10	110	165
11.10	340	340	$\frac{1}{2}$	.....	29.10	110	152
11.20	340	340	$\frac{5}{8}$	.....	29.10	110	145
11.30	325	345	$\frac{1}{2}$	.....	29.09	110	150
11.40	330	345	$\frac{1}{2}$	... .	29.09	115	160
11.50	340	350	$\frac{9}{16}$	.....	29.09	115	155
12.00 M.	350	350	$\frac{1}{2}$	76	29.09	105	172
12.10 P.M.	350	350	$\frac{1}{2}$	....	29.09	110	140
12.20	340	350	$\frac{1}{2}$	.....	29.02	110	150
12.30	380	340	$\frac{1}{2}$	.....	29.02	125	150
12.40	325	355	$\frac{1}{2}$	.....	29.03	125	158
12.50	380	340	$\frac{1}{2}$	78	29.04	115	180
1.00	340	355	$\frac{1}{2}$	78	29.05	110	145
1.10	365	345	$\frac{1}{2}$	.....	29.05	110	160
1.20	350	355	$\frac{1}{2}$	.....	29.06	115	145
1.30	375	345	$\frac{1}{2}$	74	29.06	120	160
1.40	400	340	$\frac{1}{2}$	....	29.06	125	170
1.50	340	350	$\frac{9}{16}$	.....	29.06	120	165
2.00	340	350	$\frac{1}{2}$	....	29.06	110	152
2.10	380	355	$\frac{1}{2}$	.....	29.00	110	165
2.20	345	345	$\frac{1}{2}$	....	29.06	120	160
2.30	350	355	$\frac{1}{2}$	.....	29.06	120	165
2.40	360	355	$\frac{9}{16}$	.....	29.06	110	160
2.50	350	355	$\frac{5}{8}$	.....	29.06	115	160
3.00	350	355	$\frac{1}{2}$	.....	29.06	125	155
3.10	360	355	$\frac{9}{16}$	.....	29.06	120	190
3.20	360	355	$\frac{5}{8}$	.....	29.06	125	155

TABLE XV.—*Continued.*

TEST NO. 2, ST. PAUL, MARCH 23, 1892—TEMPERATURES, ETC.

Time.	Pyrometer No. 1.	Pyrometer No. 2.	Draught Gauge.	Temperature in boiler room.	Barometer.	Feed-water temperature near economizer.	Feed water near boiler.
3.30 P.M.	350	355	¼	....	29.06	130	185
3.40	360	355	¼	.....	29.06	130	162
3.50	380	350	¼	.....	29.06	130	175
4.00	350	355	¼	.....	29.06	130	160
4.10	400	345	¼	.....	29.06	130	195
4.20	350	360	¼	.....	29.06	125	160
4.30	360	355	¼	.....	29.06	120	190
4.40	370	355	¼	74	29.06	130	180
4.50	410	350	¼	.....	29.06	140	170
5.00	380	350	¼	.....	29.06	140	175
5.10	390	335	¼	.....	29.06	145	170
5.20	320	350	¼	80	29.06	140	170
5.30	340	350	¼	.....	29.06	125	170
5.40	340	365	¼	.....	29.06	120	160
5.50	360	360	¼	.....	29 06	125	170
6.00	370	360	¼	.....	29.06	130	165
6.10	360	365	¼	.....	29.06	135	160
6.20	360	365	¼	82	29.06	130	165
6.30	380	365	¼	.....	29.06	125	170
6.40	370	365	¼	.....	29.06	130	150
6.50	380	365	¼	.....	29.06	125	155
7.00	420	360	¼	.....	29.06	130	157
7.10	360	365	¼	.....	29.06	130	165
7.20	360	360	¼	.....	29.06	125	195
7.30	370	360	¼	.....	29.06	135	160
7.40	350	365	¼	.....	29.06	120	175
7.50	360	360	¼	.....	29.06	120	155
8.00	365	365	¼	.....	29.06	120	150
8.10	370	360	¼	74	29.06	120	150
8.20	350	365	¼	.....	29.06	125	155
8.30	380	360	¼	.....	29.06	125	185
8.40	360	365	¼	.....	29.06	130	160
8.50	400	350	¼	.....	29.06	140	155
9.00	350	360	¼	.....	29.06	130	170
9.10	360	360	¼	80	29.06	140	170
9.20	350	360	¼	.....	29.06	130	170
9.30	340	360	¼	.....	29.06	120	180
9.40	450	340	¼	.....	29.06	130	187
9.50	340	350	¼	.....	29.06	130	170
10.00	380	355	¼	.....	.....	130	175
10.10	360	360	¼	.....	.....	130	170
10.20	360	360	¼	80	29.08	120	160
10.30	360	340	¼	.....	29.09	135	150
10.40	325	345	¼	.....	29.09	125	160
10.50	310	345	¼	.....	29.08	145	195
11.00	310	345	¼	80	29.08	150	165
11.10	300	345	¼	.....	29.08	130	175
11.20	320	345	¼	.....	29.08	130	160
11.30	350	330	¼	.....	29 08	145	180
11.40	340	340	¼	74	29.08	140	165
11.50	340	330	¼	.....	29.08	140	170
12.00	350	320	¼	.....	29.09	140	190
12.10 A.M.	320	325	¼	.....	29.09	140	185
12.20	360	310	¼	78	29.09	150	185
12.30	330	320	¼	.....	29.09	140	170
12.40	330	315	¼	.....	29.09	140	157
12.50	260	340	¼	.....	29.09	150	180
1.00	380	315	¼	74	29.09	130	170
1.10	320	305	¼	.....	29.09	130	155
1.20	300	320	¼	.....	29.09	125	195
1.30	320	305	¼	.....	29.09	130	180
1.40	320	315	¼	78	29.09	140	100
1.50	420	290	¼	76	29.09	150	150
2.00	260	325	¼	.....	29.09	150	185
Total	45,030	44,810	135 7/16	1,458	3,762.09	15,819	20.397
Average	344	342	⅜	77	28.64	120	155

TABLE XVI.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—COMBINED HORSE-POWER.

Time.	H.P.	Time.	H.P.	Time.	H.P.	Time.	H.P.
4.40	106.04	10.10	798.52	3.40	977.80	9.10	841.89
4.50	108.57	10.20	971.38	3.50	823.72	9.20	713 02
5.00	164.39	10.30	1,034.33	4.00	878.00	9.30	827.51
5.10	117.92	10.40	871.44	4.10	758.90	9.40	779.00
5.20	116.78	10.50	949.32	4.20	919.00	9.50	690.84
5.30	164.30	11.00	938.50	4.30	794.00	10.00	691.02
5.40	244.52	11.10	908.47	4.40	898.19	10 10	779.64
5.50	341.00	11.20	1,050.82	4.50	931.83	10.20	617.67
6.00	437.33	11.30	983.00	5.00	829.83	10.30	716.61
6.10	498.55	11.40	947.47	5.10	847.51	10.40	571.35
6.20	782.15	11.50	978.63	5.20	970.70	10.50	650.00
6.30	636.23	12.00	983.02	5.30	850.76	11.00	650.00
6.40	778.94	12.10	824.71	5.40	945.94	11.10	635.00
6.50	827.86	12.20	910.00	5.50	1,038.36	11.20	629.00
7.00	892.12	12.30	881.14	6.00	1,074.03	11.30	620.00
7.10	554.96	12.40	920.64	6.10	1,261.34	11.40	472.03
7.20	897.73	12.50	872.04	6.20	1,476.30	11.50	485.80
7.30	869.79	1.00	774.24	6.30	1,347.64	12.00	287.05
7.40	748.13	1.10	1,041.83	6.40	1,305.28	12.10	306.51
7.50	647.33	1.20	936.61	6.50	999.71	12.20	298.42
8.00	720.62	1.30	832.34	7.00	965.03	12.30	223.69
8.10	939.15	1.40	963.46	7.10	932.63	12.40	169.13
8.20	854.27	1.50	823.34	7.20	1,098.71	12.50	172.99
8.30	870.92	2.00	898.23	7.30	878.43	1.00	166.00
8.40	913.22	2.10	863.44	7.40	1,202.31	1.10	168.03
8.50	851.00	2.20	1,153.48	7.50	693.98	1.20	155.46
9.00	833.51	2.30	1.048.11	8.00	1.054.43	1.30	135.00
9.10	785.87	2.40	882.32	8.10	820.88	1.40	112.96
9.20	871.32	2.50	1,195.30	8.20	833.85	1 50	91.80
9.30	707.24	3.00	923.64	8.30	793.00	2.00	94.48
9.40	903.86	3.10	1,000.93	8.40	732.36		
9.50	763.90	3.20	687.82	8.50	763.00	Average	756.2
10.00	902.97	3.30	828.76	9.00	893.00		

TABLE XVII.

ANALYSIS OF FUEL OIL BY PROF. JAMES E. DODGE—APRIL 16, 1892.

(1) "No. 1. Sample taken from supply at Power House at 12 M., March 5, 1892."

Analysis: Hydrogen.....13.25 per cent.
Carbon.....82.29 per cent.
Evaporative value, from and at 212°—20.85 lbs. water.

(2) "No. 2. 3 P.M., March 5, 1892."

Analysis: Hydrogen.....12.88 per cent.
Carbon.....81.13 per cent.
Evaporative value, from and at 212°—20.44 lbs. water.

(3) "1st sample taken 10.20 A.M., March 9, 1892."

Analysis: Hydrogen.....13.03 per cent.
Carbon.....83.22 per cent.
Evaporative value, from and at 212°—20.85 lbs. water.

(4) "2d sample taken 1.20 P.M., March 9, 1892."

Analysis: Hydrogen.....12.63 per cent.
Carbon.....81.77 per cent.
Evaporative value, from and at 212°—20.37 lbs. water.

(5) "3d sample taken 5 P.M., March 9, 1892."

Analysis: Hydrogen.....13.34 per cent.
Carbon.....83.49 per cent.
Evaporative value, from and at 212°—21.09 lbs. water.

Average evaporative value, from and at 212°, 5 specimens—20.63 lbs. water.

TABLE XVIII.

SAMPLE CONDUCTOR'S RECORD—FIRST AVENUE AND NIC. AVENUE LINE. CAR No. 264 : C. H. BEREINGER, CONDUCTOR No. 25. DATE, MARCH 5, 1892.

Time P.M.	Location of Car.	Car Moving or Standing.	Number of Passengers.	Time P.M.	Location of Car.	Car Moving or Standing.	Number of Passengers.
11.50	38th and Nic. Ave.....	S	0	6.20	Hen. and Wash. Ave...	S	8
12.00	36th " " "	M	0	6.30	13th " 1st Ave.....	M	34
12.10	26th " " "	"	3	6.40	27th " Nic. "	"	21
12.20	7th " 1st "	"	3	6.50	38th " " "	S	0
12.30	Hen. " Wash. Ave .	"	2	7.00	36th " " "	M	2
12.40	Grant and 1st Ave.....	"	17	7.10	26th " " "	"	10
12.50	29th and Nic. Ave.....	"	5	7.20	7th " 1st "	"	13
1.00	Car No. 287.....	...	0	7.30	Hen. " Wash. Ave...	S	6
1.10	35th and Nic. Ave.....	M	1	7.40	13th " 1st Ave.....	M	7
1.20	38th " " "	S	0	7.50	28th " Nic. "	"	6
1.30	30th " " "	M	7	8.00	38th " " "	S	0
1.40	14th " " "	"	14	8.10	36th " " "	M	0
1.50	2d " 1st "	"	2	8.20	26th " " "	"	8
2.00	7th " " "	"	5	8.30	8th " 1st "	"	15
2.10	24th " Nic. "	"	0	8.40	Hen. " Wash. Ave...	S	0
2.20	34th " " "	"	0	8.50	Grant " 1st Ave.....	M	9
2.30	38th " " "	S	1	9 00	29th " Nic. "	"	1
2.40	30th " " "	M	3	9.10	38th " " "	S	0
2.50	14th " " "	"	14	9.20	38th " " "	"	0
3.00	2d " 1st "	"	2	9.30	27th " " "	M	5
3.10	8th " " "	"	5	9.40	10th " 1st "	"	9
3.20	24th " Nic. "	"	5	9.50	Union Depot.....	"	2
3.30	34th " " "	"	1	10.00	5th and 1st Ave.....	S	14
3.40	38th " " "	S	0	10.10	15th " Nic. "	M	15
3.50	30th " " "	M	9	10.20	28th " " "	"	8
4.00	14th " " "	"	16	10.30	33d " " "	"	5
4.10	2d " 1st "	"	0	10.40	30th " " "	"	0
4.20	7th " " "	"	12	10.50	Grant.....	"	1
4.30	24th " Nic. "	"	11	11.00	2d St. and 1st Ave.....	"	0
4.40	.....	.....	.....	11.10	6th " " "	"	15
4.50	.....	.....	.....	11.20	24th " Nic. "	"	16
5.00	.....	.....	.....	11.30	35th " " "	"	3
5.10	.....	.....	.....	11.40	38th " " "	S	0
5.20	Car No. 264.....	.....	.....	11.50	32d " " "	M	1
5.30	.....	.....	.....	A.M.			
5.40	38th and Nic. Ave.....	S	0	12.00	17th " " "	"	7
5.50	36th " " "	M	0	12.10	3d " 1st "	"	4
6.00	26th " " "	"	15	12.20	4th " " "	"	10
6.10	7th " 1st "	"	15	12.30	25th " Nic. "	"	10

TABLE XIX.

TEST NO. 3*b*, OF THIRTY-FIRST STREET PLANT, MINNEAPOLIS, OCTOBER 26, 1892—FEED-WATER RECORD.

Time.	Tank 1, full.	Tank 1, empty.	Sent to Tank 3.	Tank 2, full.	Tank 2, empty.	Sent to Tank 3.	Ht. in 3.	Temp. in 3.
5.00	.....	.....	.....	4,430	.....	.....	6	62
5.10	.....	.....	.....	.....	2,932	1,498	6	62
5.20	4,395	.....	.....	2,932	1,491	1,441	6	61.5
5.30	.....	3.475	920	4,435	.....	.....	6	60.5
5.40	3.475	2,320	1,155	.....	.....	.....	6	60
5.50	4,330	.....	.....	.....	3,520	915	6	59.5
6.00	.....	.....	.....	3.520	2,511	1,009	6	59
6.10	.....	4.132	199	2,511	1,063	1,448	6	59
6.20	4,132	2,145	.....	4,370	.....	.....	6	59
6.30	2,145	1,009	1,136	.....	3,438	932	6	59
6.40	4,830	.....	.....	3,438	1,242	1,196	6	59
6.50	.....	1,295	1,535	5,863	4,993	970	6	59
7.00	4,850	.....	.....	4,993	2,495	2,498	6	58.5
7.10	.....	3,326	1,524	2,495	1,138	1,357	6	57.5
7.20	3,326	1.200	3,126	4,685	3,792	993	6	56.5
7.30	4,698	3,582	1,116	3,792	1,287	1,505	6½	56
7.40	3,582	1,085	1,497	4,742	4,267	475	6	56
7.50	5,120	3.533	1,687	4,267	1,220	2,947	6	57
8.00	2.533	1,150	1,388	5,265	3,405	1.860	6	56
8.10	4,655	3.807	848	3,405	1,175	2,230	6	56
8.20	3,807	1,072	2,735	4,650	4,346	304	6	55
8.30	4,664	.....	.....	4,346	1,382	2,964	6	55
8.40	.....	1,252	3,206	4,670	1,088	3,582	6	55
8.50	4,722	.....	.....	.....	.....	.....	6	.....
9.00	.....	1,283	3,439	4,866	.....	.....	6	55
9.10	4,681	.....	.....	.....	1,211	3,655	6	55
9.20	.....	1,114	3,567	4,976	.....	.....	6	55
9.30	4,291	.....	.....	.....	1,174	3,892	6	56
9.40	.....	1.092	3,199	4,766	.....	.....	6	55
9.50	5,096	.....	.....	.....	1,220	3,546	6	55
10.00	.....	1,179	3,917	6.265	.....	.....	6	55
10.10	5,104	.....	.....	.....	2,592	3,673	6	56
10.20	.....	2,008	3,096	4.425	.....	.....	6	54
10.30	4,446	.....	.....	.....	1,497	2,928	6	56
10.40	.....	1,485	2,961	4,690	.....	.....	6	54½
10.50	4,546	.....	.....	.....	1,597	3,093	6	55
11.00	.....	1,477	3,069	4,650	.....	.....	6	55
11.10	4,514	.....	.....	.....	1,650	3.000	6	55
11.20	.....	1,636	2,878	4,635	.....	.....	6	55
11.30	4,640	.....	.....	.....	1,450	3,180	6	54½
11.40	.....	1,700	2,940	4.846	.....	.....	6	55
11.50	5,111	.....	.....	.....	1,775	3,071	6	55
12.00	.....	2,117	2,994	4,880	.....	.....	6	55
12.10	5,135	.....	.....	.....	1,600	3,280	6	55
12.20	.....	1,885	3,250	4,710	.....	.....	6	55
12.30	4,413	.....	.....	.....	1,200	3,510	7	55
12.40	.....	1,110	3.303	5,085	4,230	855	6	54½
12.50	5,150	4,060	1,090	4,230	1,062	3,168	6	54½
1.00	4,060	1,126	3,934	4,617	4,066	551	6	54½
1.10	5,240	3,350	1,890	4,066	1,239	2,727	6	54½
1.20	5,255	.....	.....	5,879	2,225	3,654	6	54½
1.30	.....	1,975	3,280	5.246	.....	.....	6	55
1.40	5,265	.....	.....	.....	1,685	3,561	6	55
1.50	.....	1,835	3,430	4,980	.....	.....	6	55
2.00	5,020	.....	.....	.....	1,511	3,469	6	55
2.10	.....	1,370	3,650	5,100	.....	.....	6	55
2.20	5,055	.....	.....	.....	1,300	3,800	6	55
2.30	.....	1,380	3,675	5,070	.....	.....	6	55
2.40	5,200	.....	.....	.....	1,700	3,370	6	55
2.50	.....	1,825	3,375	5,165	.....	.....	6	55½
3.00	5,032	.....	.....	.....	2,200	3,965	6	55
3.10	.....	1,870	3,112	5.000	.....	.....	6	55
3.20	5,000	.....	.....	.....	1,580	3,420	6	55
3.30	.....	1,745	3,255	5,000	.....	.....	6	55
3.40	5,043	.....	.....	.....	1,700	3.300	6	55
3.50	.....	1,850	3,193	5,075	.....	.....	6	55
4.00	3,050	.....	.....	.....	1,805	3,270	6	55
4.10	.....	1.950	3,100	4,970	.....	.....	6	55

TABLE XIX.—*Continued.*

TEST NO. 35, OF THIRTY-FIRST STREET PLANT, MINNEAPOLIS, OCTOBER 26, 1892—FEED-WATER RECORD.

Time.	Tank 1, full.	Tank 1, empty.	Sent to Tank 3.	Tank 2, full.	Tank 2, empty.	Sent to Tank 3.	Ht. in 3.	Temp. in 3.
4.20	5,040				1,750	3,220	6	55
4.30		2,160	2,880	4,130			6	55
4.40	5,000				1,450	3,180	6	55
4.50		1,780	3,220	5,340			6	55
5.00	5,020				1,900	3,440	6	55
5.10		1,650	3,370	5,000			6	55
5.20	5,350				1,080	3,920	6	55
5.30		1,760	3,590	5,100			6	55
5.40	5,525	4,040	1,485		1,350	3,750	6	55
5.50	4,040	1,210	2,830	6,967	6,180	787	6	55
6.00	5,525			6,180	3,450	2,730	6	55
6.10		2,520	3,005	5,285			6	55
6.20	6,000				1,825	3,460	6	55
6.30		1,750	4,250	5,200			6	55
6.40	5,080				1,450	3,750	6	55
6.50		1,880	3,200	6,100			6	55
7.00	5,850				1,440	4,560	6	55
7.10		1,900	3,950	6,080			6	55
7.20	6,030				1,550	3,530	6	54
7.30		1,730	4,300	6,100			6	54
7.40	6,000				2,360	3,640	6	55
7.50		2,230	3,770	6,050			6	54
8.00	6,050				2,370	3,680	6	55
8.10		2,720	3,330	6,030			6	55
8.20	6,000				2,980	3,050	6	55
8.30		3,150	2,850	6,000			6	55
8.40	5,210				2,820	3,180	6	55
8.50		2,180	3,030	5,050			6	55
9.00	4,800				2,050	3,000	6	55
9.10		2,060	2,740	5,010			6	55
9.20	4,800				2,400	2,610	6	55
9.30		2,640	2,160	4,800			6	55
9.40	4,800				2,580	2,220	6	55
9.50		2,600	2,200	4,980			6	55
10.00	4,800				2,750	2,230	6	55
10.10		2,580	2,220	4,815			6	55
10.20	4,900				2,560	2,255	6	55
10.30		3,040	1,860	4,813			6	55
10.40	5,000				2,850	1,963	6	55
10.50		3,230	1,770	4,800			6	55
11.00	3,800				3,580	1,220	6	55
11.10		2,155	1,645	4,335			6	55
11.20	4,800				2,650	1,685	6	55
11.30		2,495	2,305	4,815			6	55
11.40	4,830				2,500	2,315	6	56
11.50		2,825	2,005	4,815			6	55
12.00	4,800				2,850	1,965	6	55
12.10		3,400	1,400	4,800			6	55
12.20	4,800				3,200	1,600	6	55
12.30		3,070	1,730	4,800			6	55
12.40	4,800				2,875	1,925	6	55
12.50		2,370	2,430	4,800			6	55
1.00	4,800				2,850	1,950	6	55
1.10		3,030	1,770	4,800			6	55
1.20	4,800				3,200	1,600	6	55
1.30		4,010	790	4,950			6	55

TABLE XX

TEST NO. 3*b*, OF THIRTY-FIRST STREET PLANT, MINNEAPOLIS, OCTOBER 26, 1892—REVOLUTIONS, STEAM PRESSURE, HT. OF WATER IN BOILERS.

Time.	Rev., Engine 1.	Rev., Engine 2.	Rev., Engine 3.	Rev., Engine 4.	Steam Pressure in Boiler Room.	Ht., Boiler 1.	Ht., Boiler 2.	Ht., Boiler 3.
5.00	.....	.....	.....	250	133	6¾	5½	5½
5.10	.....	.....	.....	250	135	1	−1½	0
5.20	.....	.....	.....	249	134	1½	−1	0
5.30	.....	.....	.....	249	138	1½	0	− ¼
5.40	.....	.....	.....	249½	134	¾	1½	− ½
5.50	.....	.....	.....	249	134	5¼	5½	−1
6.00	.....	.....	.....	246¼	134	4½	5	−1¼
6.10	.....	.....	.....	247	135	5	6¼	−1
6.20	.....	.....	.....	245	135	4¼	6	− ¾
6.30	.....	.....	.....	242	135	4¾	5¼	0
6.40	.....	.....	.....	241	136	5	6	1
6.45	.....	.....	238	.....	.....	.....	.....	.....
6.50	.....	.....	239	241	137	4½	5	1½
7.00	248½	.....	248½	248	140	1½	2	1
7.10	249	.....	249½	248	136	−1½	1½	¾
7.20	247½	.....	249½	248	137	−1	½	1
7.30	248	.....	247	246½	135	− ½	− ¾	1
7.40	248	.....	249	247½	135	−1	−1½	5½
7.50	250	.....	250	248	138	1½	3	2¾
8.00	248	.....	249	247	137	3	3½	1
8.10	248½	.....	250	248	135	2¾	4	¾
8.20	249	.....	249	247	139	2½	3½	− ½
8.30	247½	.....	249	247	135	¾	3½	¼
8.40	248¾	.....	250	247	137	2¼	4	− ¾
8.50	244	.....	243½	253	138	¾	2½	−1½
9.00	244	.....	247	.....	137	2¼	2	− ¼
9.10	242	.....	246	.....	136	2¼	2¾	− ½
9.20	242½	.....	242	.....	136	3	3½	− ¾
9.30	246	.....	243	.....	137	2	3	1½
9.40	244½	.....	245	.....	137	¾	3	1
9.50	247	.....	248	.....	140	¾	3¾	2½
10.00	244	.....	246	.....	139	2	4	.....
10.10	245½	.....	246½	.....	134	2	4½	2¾
10.20	245	.....	244	.....	136	2	2¾	¾
10.30	247½	.....	247	.....	137	3	2¼	−1
10.40	245½	.....	245½	.....	135	2¼	4	−1½
10.50	246	.....	249	.....	136	0	3½	−1½
11.00	248½	.....	245	.....	138	2	2¼	¾
11.10	240	.....	245	.....	147	2¼	3	¾
11.20	244	.....	248	.....	140	1¼	¾	−1
11.30	243	.....	243	.....	136	¾	3	− .5
11.40	238	.....	244	.....	134	2¾	2	− .75
11.50	240	.....	242	.....	138	− .5	3	−1.25
12 00	246	250	248½	.....	139	−1.5	1	.5
12.10	249	250	249	.....	136	.25	.5	− .5
12.20	248	250	250	.....	136	1.5	1	−.2
12.30	249½	250	249	.....	136	1.25	3	.....
12 40	247	249	249½	.....	135	.....	3	.....
12.50	247½	248	251	.....	137	2	2	−1.5
1.00	245½	248	249½	.....	137	.25	2.5	.5
1.10	245	247½	250	.....	137	1	4	2
1.20	247½	250	250	.....	138	1	3.5	.....
1.30	248¼	248½	247	.....	139	1.5	2.5	1
1.40	246	248	251	.....	137	.5	3	.....
1.50	249½	250	250	.....	138	.....	2.75	1.25
2.00	248	248	250	.....	136	2.5	2.5	−1
2.10	248	248½	249	.....	137	1.75	1.5	2
2.20	247	252	251	.....	139	1.5	2	1.25
2.30	249	249	249½	.....	137	2	2.5	.....
2.40	247	249	249	.....	134	2.5	3.25	2.25
2.50	247	249	248¾	.....	137	1.75	3.5	1
3.00	246	251	250	.....	137	2	3	− .75
3.10	247½	246½	251	.....	140	2.5	3	−1
3.20	248¼	248	250	.....	141	1.25	.....	1.75
3.30	.....	249½	250	249	140	1	3.5	.5
3.40	.....	248½	249	250	138	.5	3	−1
3.50	.....	250	250	250	138	2.5	3	− .5

TABLE XX.—*Continued.*

TEST NO. 3*b*, OF THIRTY-FIRST STREET PLANT, MINNEAPOLIS, OCTOBER 26, 1892—REVOLUTIONS, STEAM PRESSURE, HT. OF WATER IN BOILERS.

Time	Rev., Engine 1.	Rev., Engine 2.	Rev., Engine 3.	Rev., Engine 4.	Steam Pressure in Boiler Room.	Ht., Boiler 1.	Ht., Boiler 2.	Ht., Boiler 3.
4.00	.....	249	251	247½	137	2.5	2.5	— .25
4.10	.....	246½	249½	248	140	2.5	3	—1
4.20	.....	247	249	249½	135	2	1.5	—3.5
4.30	.....	246½	249	247	137	— .25	3	—2.5
4.40	.....	247	248	246	138	.....	2	—1.75
4.50	.....	250	250	248	137	.....	2.5	—1.5
5.00	.....	250	245	246	137	.....	3.5	—2.5
5.10	.....	247	245¼	248	134	—5.5	2.5	.....
5.20	.....	246	246	246¼	143	—1	.5	4.5
5.30	.....	247	246½	248	138	1.5	2.5	.....
5.40	.....	246½	246	247	137	2	4.5	.....
5.50	.....	244	245	247	136	3	4	1.5
6.00	.....	249	248	245	138	1	1.5	.....
6.10	.....	247	250	249	137	2.25	2	— .25
6.20	.....	248	248	245½	140	.....	2.25	.....
6.30	.....	247	245½	247	139	.75	1	—1
6.40	.....	245	244	243	138	— .5	2.5	— .5
6.50	244	246	.....	245	136	— .5	.25	— .25
7.00	247	246	254	247	137	— .75	1.5	— .75
7.10	246½	.....	249	245½	138	.5	1.25	—1.25
7.20	245	.....	243	247¼	137	1.25	1	—2
7.30	246	.....	247	246	137	.5	2.5	0
7.40	247	.....	245	246	139	.0	2.75	.25
7.50	248	.....	248	246	138	1.25	2	.25
8.00	247½	.....	249	248	137	2.5	1.5	0
8.10	248½	.....	248	248½	138	.75	.75	0
8.20	249	.....	247	246½	134	.25	.5	— .5
8.30	247	.....	250	246	135	.5	.5	— .25
8.40	249	.....	249½	248	138	.75	1	—1
8.50	246	.....	249	empty	136	.5	.75	— .5
9.00	246½	.....	248½	255	137	1.5	2.5	0
9.10	247½	.....	247½	.....	141	.25	1.5	1.5
9.20	246	.....	246½	.....	129	.5	3	— .5
9.30	249	.....	248	.....	141	.75	—2.5	.5
9.40	248	.....	247	.....	140	—1.5	2	0
9.50	248	.....	249	.....	138	0	4	— .5
10.00	249½	.....	249½	.....	138	—1.5	2.5	0
10.10	247½	.....	249	.....	137	0	.5	1.5
10.20	248	.....	249½	.....	136	0	1.5	3
10.30	250	.....	249	.....	139	— .25	.25	3.5
10.40	248	.....	248½	.....	137	— .25	0	2
10.50	247	.....	248	.....	136	— .25	1	1
11.00	248	.....	248	.....	140	—2	.5	.5
11.10	248	.....	249	.....	137	—1	1	— .5
11.20	249½	.....	249	.....	136	—2	.25	0
11.30	250	.....	247	.....	137	—1	.5	.25
11.40	247½	.....	249	.....	138	— .75	.5	.5
11.50	248	.....	249	.....	140	—1.25	.25	.5
12.00	.....	.....	244	.....	136	—2.25	—1	0
12.10	.....	.....	250	.....	135	—2	— .5	—1
12.20	.....	.....	250	.....	139	—1.25	— .5	0
12.30	.....	.....	250	.....	139	—1.5	— .25	— .2
12.40	.....	.....	250	.....	138	.25	0	— .2
12.50	.....	.....	253	.....	136	.5	.25	.2
1.00	.....	.....	249½	.....	141	(.75?)	.5	2
1.10	.....	.....	251	.....	140	1	.25	1.75
1.20	.....	.....	253	.....	137	2	1.5	.25
1.30	.....	.....	252	.....	140	2	2	.5
					131.5 } corrected. }			

TABLE XXI.

TEST NO. 3*b*, OF THIRTY-FIRST STREET PLANT, OCTOBER 26, 1892—COMBINED HORSE-POWER.

Time.	Horse-power.	Time.	Horse-power.	Time.	Horse-power.
4.50	81.93	11.50	523.76	6.50	823.80
5.00	123.78	12.00	631.27	7.00	654.92
5.10	116.54	12.10	725.19	7.10	540.195
5.20	99.702	12.20	749.40	7.20	569.015
5.30	121.17	12.30	623.43	7.30	660.92
5.40	175.53	12.40	558.52	7.40	654.85
5.50	328.89	12.50	649.81	7.50	624.60
6.00	396.01	1.00	739.52	8.00	562.395
6.10	373.87	1.10	671.70	8.10	583.86
6.20	604.30	1.20	760.51	8.20	544.75
6.30	555 25	1.30	590.18	8.30	584.59
6.40	657.37	1.40	621.18	8.40	576.41
6.50	637.91	1.50	576.57	8.50	396.91
7.00	618.42	2.00	665.13	9.00	436.83
7.10	526.39	2.10	738.61	9.10	407.95
7.20	669.66	2.20	479.89	9.20	418.52
7.30	677.12	2.30	643.23	9.30	490.18
7.40	522.28	2.40	563.66	9.40	383.40
7.50	692.99	2.50	567.16	9.50	.....
8.00	645.75	3.00	517.26	10.00	.....
8.10	782.80	3.10	603.08	10.10	284.86
8.20	653.61	3.20	654.59	10.20	400 22
8.30	569.12	3.30	531.13	10.30	369.26
8.40	478.08	3.40	695.52	10.40	430.05
8.50	573.78	3.50	594.39	10.50	394.94
9.00	425.98	4.00	504.71	11.00	440.10
9.10	333.09	4.10	594.17	11.10	527.63
9.20	583.91	4.20	509.04	11.20	308.58
9.30	644.30	4.30	607.27	11.30	387.86
9.40	558.44	4.40	714.42	11.40	306.65
9.50	584.92	4.50	692.74	11.50	322.85
10.00	574.33	5.00	631.04	12.00	328.73
10.10	641.69	5.10	767.86	12.10	212.62
10.20	375.45	5.20	697.40	12.20	195.48
10.30	548.79	5.30	819.72	12.30	237.43
10.40	494.45	5.40	757.86	12.40	131.92
10.50	597.10	5.50	901.24	12.50	150.78
11.00	364.95	6.00	723.64	1.00	77.49
11.10	545.50	6.10	675.65	1.10	77.95
11.20	584.81	6.20	622.65	1.20	80.09
11.30	490.94	6.30	629.09	1.30	79.90
11.40	664.20	6.40	745.91		
					522.5 av.

TABLE XXII.

Test No. 1, Minneapolis, March 5, 1892—Ratio of Moving Cars to Total Cars.

Time.	Moving Cars.	Total Cars.	Ratio.	Time.	Moving Cars.	Total Cars.	Ratio.
5.00	.....	.....	.....	3.30	109	135	.807
5.10	2	2	1.	3.40	115	133	.864
5.20	5	5	1.	3.50	116	138	.840
5.30	12	12	1.	4.00	102	135	.755
5.40	27	28	.964	4.10	110	136	.809
5.50	42	46	.914	4.20	112	137	.817
6.00	64	68	.950	4.30	110	138	.797
6.10	91	100	.910	4.40	115	143	.804
6.20	94	122	.727	4.50	111	140	.792
6.30	121	136	.890	5.00	109	142	.767
6.40	116	148	.784	5.10	103	140	.735
6.50	117	146	.801	5.20	113	142	.795
7.00	122	139	.878	5.30	108	138	.782
7.10	115	142	.810	5.40	117	152	.769
7.20	124	146	.849	5.50	122	155	.787
7.30	110	138	.797	6.00	122	160	.762
7.40	127	145	.876	6.10	120	160	.750
7.50	128	147	.871	6.20	130	166	.783
8.00	116	144	.806	6.30	134	162	.827
8.10	127	139	.914	6.40	129	159	.811
8.20	116	141	.823	6.50	120	148	.810
8.30	117	134	.803	7.00	118	148	.797
8.40	106	135	.785	7.10	111	145	.765
8.50	117	136	.860	7.20	119	145	.820
9.00	115	135	.852	7.30	114	143	.797
9.10	112	138	.812	7.40	110	142	.774
9.20	126	136	.926	7.50	111	140	.792
9.30	109	133	.820	8.00	115	137	.839
9.40	112	138	.812	8.10	108	131	.824
9.50	118	136	.868	8.20	108	129	.837
10.00	115	134	.858	8.30	102	117	.871
10.10	111	130	.854	8.40	102	120	.850
10.20	113	135	.837	8.50	101	109	.926
10.30	104	131	.794	9.00	93	96	.969
10.40	111	139	.798	9.10	87	102	.853
10.50	107	139	.770	9.20	81	94	.861
11.00	108	133	.812	9.30	73	91	.802
11.10	104	130	.800	9.40	75	86	.872
11.20	115	139	.827	9.50	82	91	.901
11.30	110	136	.809	10.00	72	85	.847
11.40	118	135	.874	10.10	67	88	.761
11.50	110	133	.827	10.20	71	83	.891
12.00	112	133	.842	10.30	70	81	.864
12.10	109	137	.795	10.40	68	83	.818
12.20	114	141	.809	10.50	68	83	.818
12.30	105	135	.778	11.00	56	72	.777
12.40	119	135	.881	11.10	75	81	.926
12.50	123	143	.860	11.20	78	83	.939
1.00	113	136	.830	11.30	67	81	.827
1.10	118	141	.837	11.40	75	87	.862
1.20	116	140	.829	11.50	76	82	.926
1.30	114	137	.832	12.00	61	71	.859
1.40	114	144	.791	12.10	61	70	.871
1.50	113	137	.825	12.20	54	57	.947
2.00	114	142	.803	12.30	42	46	.913
2.10	106	137	.773	12.40	34	35	.971
2.20	106	136	.778	12.50	23	23	1.000
2.30	111	137	.810	1.00	13	17	.928
2.40	114	136	.838	1.10	9	9	.....
2.50	109	134	.813	1.20	.....	7	.....
3.00	94	129	.729	1.30	.....	4	.....
3.10	105	133	.789	1.40	.....	1	.....
3.20	108	131	.824		Average ratio.....		.811

TABLE XXIII.

TEST NO. 2, ST. PAUL, FEBRUARY 23, 1892—RATIO OF MOVING CARS TO TOTAL CARS.

Time.	Mov. Cars.	Total Cars.	Ratio.	Time.	Mov. Cars.	Total Cars.	Ratio.
5.00	1	1	1.	3.30	44	63	.698
5.10	1	1	1.	3.40	48	64	.750
5.20	1	2	.5	3.50	46	63	.730
5.30	2	3	.666	4.00	45	63	.714
5.40	4	7	.571	4.10	44	63	.698
5.50	13	17	.764	4.20	51	65	.784
6.00	22	29	.758	4.30	43	64	.671
6.10	26	37	.702	4.40	44	66	.666
6.20	31	48	.645	4.50	50	66	.757
6.30	34	53	.641	5.00	50	68	.705
6.40	44	57	.772	5.10	50	72	.694
6.50	52	64	.812	5.20	49	75	.653
7.00	44	67	.657	5.30	50	72	.694
7.10	52	69	.753	5.40	53	73	.726
7.20	42	71	.591	5.50	51	76	.671
7.30	55	70	.786	6.00	51	76	.671
7.40	53	70	.757	6.10	52	79	.658
7.50	54	74	.730	6.20	53	75	.706
8.00	45	69	.652	6.30	53	74	.716
8.10	51	67	.761	6.40	53	72	.736
8.20	50	68	.735	6.50	58	71	.816
8.30	46	66	.697	7.00	49	69	.710
8.40	50	64	.781	7.10	51	69	.739
8.50	55	65	.846	7.20	43	68	.632
9.00	47	63	.746	7.30	49	69	.710
9.10	45	62	.726	7.40	45	66	.681
9.20	48	63	.762	7.50	47	65	.723
9.30	49	63	.778	8.00	45	66	.681
9.40	48	62	.774	8.10	45	64	.703
9.50	53	62	.855	8.20	48	63	.762
10.00	36	62	.581	8.30	42	63	.667
10.10	50	63	.794	8.40	47	63	.778
10.20	48	63	.762	8.50	54	64	.843
10.30	48	62	.774	9.00	51	63	.809
10.40	47	60	.783	9.10	46	62	.742
10.50	49	61	.803	9.20	44	63	.698
11.00	50	63	.794	9.30	53	63	.841
11.10	42	65	.646	9.40	48	63	.762
11.20	50	63	.794	9.50	48	63	.762
11.30	45	64	.703	10.00	39	60	.650
11.40	45	63	.714	10.10	47	58	.810
11.50	49	64	.766	10.20	44	56	.785
12.00	51	65	.785	10.30	46	54	.851
12.10	45	63	.714	10.40	43	53	.811
12.20	48	62	.774	10.50	32	52	.615
12.30	47	65	.723	11.00	35	52	.673
12.40	52	65	.800	11.10	37	49	.755
12.50	49	66	.742	11.20	32	45	.711
1.00	41	64	.641	11.30	38	42	.904
1.10	47	63	.746	11.40	28	37	.756
1.20	48	65	.738	11.50	25	31	.806
1.30	45	65	.692	12.00	12	24	.500
1.40	51	64	.797	12.10	14	16	.875
1.50	49	65	.754	12.20	9	12	.750
2 00	45	64	.703	12.30	6	8	.750
2.10	49	64	.766	12.40	6	8	.750
2.20	46	64	.719	12.20	2	3	.666
2.30	39	64	.609	1.00	1	2	.500
2.40	46	62	.742	1.10	1	2	.500
2.50	51	63	.809	1.20			
3.00	45	63	.714	1.30		Average ratio..	.730
3.10	42	63	.667	1.40			
3.20	50	63	.794	1.50			

TABLE XXIV.

TEST NO. 1, POWER HOUSE NO. 1, MINNEAPOLIS, MARCH 5, 1892—MECHANICAL HORSE-POWER AND NUMBER OF MOVING CARS, ALSO HORSE-POWER PER CAR.

Time.	Total H.P.	No. of cars.	H.P. per car.	Time.	Total H.P.	No. of cars.	H.P. per car.
4.20	102.64	.....	.....	3.20	1,191.05	131	9.09
4.30	216.71	.....	.....	3.30	1,462.65	135	10.83
4.40	211.99	.....	.....	3.40	1,369.68	133	10.29
4.50	178.11	.....	.....	3.50	1,341.81	138	9.72
5.00	128.84	.....	.....	4.00	1,521.25	135	11.26
5.10	176.41	2	88.20	4.10	1,432.41	136	10.53
5.20	176.65	5	35.33	4.20	1,367.82	137	9.98
5.30	208.32	12	17.36	4.30	1,583.24	138	11.47
5.40	399.19	28	14.26	4.40	1,431.10	143	10.00
5.50	508.40	46	11.05	4.50	1,445.13	140	10.32
6.00	813.77	68	11.96	5.00	1,481.07	142	10.43
6.10	960.74	100	9.61	5.10	1,711.19	140	12.22
6.20	1,248.46	122	10.23	5.20	1,504.72	142	10.59
6.30	911.14	136	6.69	5.30	1,415.31	138	10.26
6.40	1,518.41	148	10.26	5.40	1,480.51	152	9.74
6.50	1,489.05	146	10.19	5.50	1,997.61	155	12.88
7.00	1,443.34	139	10.38	6.00	1,880.14	160	11.75
7.10	1,097.87	142	7.73	6.10	1,786.14	160	11.16
7.20	1,301.88	146	8.91	6 20	1,884.74	166	11.35
7.30	1,417.68	138	10.27	6.30	1,470.30	162	9.07
7.40	1,345.96	145	9.28	6.40	1,470.68	159	9.25
7.50	1,600.09	147	10.88	6.50	1,759.91	148	11.89
8.00	1,217.82	144	8.46	7.00	1,692.00	148	11.43
8.10	1,321.90	139	9.51	7.10	1,579.65	145	10.89
8.20	1,434.53	141	10.17	7.20	1,829.41	145	12.61
8.30	1,391.97	134	10.38	7.30	1,426.75	143	9.97
8.40	1,355.75	135	10.04	7.40	1,389.73	142	9.78
8.50	1,578.14	136	11.60	7.50	1,774.05	140	12.67
9.00	1,230.28	135	9.11	8.00	1,726.86	137	12.60
9.10	1,400.74	138	10.15	8.10	1,147.91	131	8.76
9.20	1,305.01	136	9.59	8.20	1,565.16	129	12.13
9.30	1,465.60	133	11.02	8.30	1,557.29	117	13.31
9.40	1,527.70	138	11.07	8.40	1,366.22	120	11.38
9.50	1,279.48	136	9.40	8.50	1,376.50	109	12.62
10.00	1,024.09	134	7.64	9.00	1,079.48	96	11.24
10.10	1,443.91	130	11.10	9.10	1,114.18	102	10.92
10.20	1,383.51	135	10.25	9.20	1,038.60	94	11.04
10.30	1,473.75	131	11.25	9.30	1,026.04	91	11.27
10.40	1,344.97	139	9.67	9.40	905.91	86	9.43
10.50	1,373.72	139	9.88	9.50	1,165.21	91	12.80
11.00	1,276.40	133	9.74	10.00	895.54	85	10.53
11.10	1,325.65	130	10.19	10.10	920.61	88	10.46
11.20	1,470.02	139	10.58	10.20	889.94	83	10.72
11.30	1,363.73	136	10.02	10.30	1,172.92	81	14.48
11.40	1,221.74	135	9.05	10.40	811.96	83	9.78
11.50	1,547.14	133	11.63	10.50	1,128.52	83	13.59
12.00	1,306.98	133	9.82	11.00	820.56	72	11.39
12.10	1,426.68	137	10.41	11.10	937.75	81	11.57
12.20	1,287.18	141	9.13	11.20	1,046.98	83	12.61
12.30	1,309.82	135	9.70	11.30	989.84	81	12.22
12.40	1,317.78	135	9.76	11.40	1,015.33	87	10.52
12.50	1,374.32	143	9.61	11.50	987.90	82	12.07
1.00	1,365.51	136	10.04	12.00	724.95	71	10.21
1.10	1,417.12	141	10.05	12.10	951.25	70	13.58
1.20	1,494.23	140	10.67	12.20	786.32	57	13.79
1.30	1,516.50	137	11.06	12.30	768.78	46	16.71
1.40	1,386.65	144	9.62	12.40	365.09	35	10.43
1.50	1,440.06	137	10.51	12.50	568.35	23	24.71
2.00	1,459.51	142	10.27	1.00	377.77	14	26.98
2.10	1,290.69	137	9.42	1.10	383.25	9	42.65
2.20	1,380.19	136	10.15	1.20	196.48	7	26.64
2.30	1,473.36	137	10.75	1.30	215.88	4	53.97
2.40	1,529.84	136	11.25	1.40	.....	.....	
2.50	1,556.84	134	11.62	1.50	.....	.....	Average
3.00	1,352.99	129	10.48	2.00	.....	.....	H.P. per car
3.10	1,173.80	133	8.82				=12.562

TABLE XXV.

TEST NO. 2, ST. PAUL, MARCH 23, 1892—MECHANICAL HORSE-POWER AND NUMBER OF MOVING CARS, ALSO HORSE-POWER PER CAR.

Time.	Total Horse-power.	No. of Cars.	H'rse-p'wer per Car.	Time.	Total Horse-power.	No. of Cars.	H'rse-p'wer per Car.
4.40	....	....	....	3.10	1,000.93	42	23.83
4.50	....	....	....	3.20	687.82	50	13.75
5.00	164.39	1	164.39	3.30	828.76	44	18.83
5.10	117.92	1	117.92	3.40	977.80	48	20.37
5.20	116.78	1	116.78	3.50	823.72	46	17.90
5.30	164.30	2	82.15	4.00	878.00	45	19.51
5.40	244.52	4	61.13	4.10	758.90	44	17.24
5.50	341.00	13	26.23	4.20	919.00	51	18.01
6.00	437.33	22	19.88	4.30	794.00	43	18.46
6.10	498.55	26	19.14	4.40	898.19	44	20.41
6.20	782.15	31	25.23	4.50	931.83	50	18.63
6.30	636.23	34	18.71	5.00	829.83	50	16.59
6.40	778.94	44	17.70	5.10	847.51	50	16.95
6.50	827.86	52	15.92	5.20	970.70	49	19.81
7.00	892.12	44	20.27	5.30	850.76	50	17.01
7.10	554.96	52	10.67	5.40	945.94	53	17.84
7.20	897.73	42	21.37	5.50	1,038.36	51	20.36
7.30	869.79	55	15.81	6.00	1,074.03	51	21.07
7.40	748.15	53	14.11	6.10	1,261.34	52	24.25
7.50	647.33	54	11.99	6.20	1,476.30	53	27.85
8.00	720.62	45	16.01	6.30	1,347.64	53	25.42
8.10	939.15	51	18.41	6.40	1,305.28	53	24.62
8.20	854.27	50	17.08	6.50	999.71	58	17.23
8.30	870.92	46	18.93	7.00	965.03	49	19.69
8.40	913.22	50	18.26	7.10	932.63	51	18.28
8.50	851.00	55	15.47	7.20	1,098.71	43	25.55
9.00	833.51	47	17.74	7.30	878.43	49	17.92
9.10	785.87	45	17.46	7.40	1,202.31	45	26.71
9.20	871.32	48	18.15	7.50	693.98	47	14.76
9.30	707.24	49	14.43	8.00	1,054.43	45	23.43
9.40	903.86	48	18.83	8.10	820.88	45	18.24
9.50	763 90	53	14.41	8.20	833.85	48	17.37
10.00	902.97	36	25.07	8.30	793.00	42	18.88
10.10	798.52	50	15.97	8.40	733.36	49	14.96
10.20	971.38	48	20.23	8 50	763.00	54	14.12
10.30	1,034.33	48	21.54	9.00	893.00	51	17.51
10.40	871.44	47	18.54	9.10	841.89	46	16.20
10.50	949.32	49	19.37	9.20	713.02	44	15.61
11.00	938.50	50	18.77	9.30	827.51	53	15.61
11.10	908.47	42	21.63	9.40	779.00	48	16.23
11.20	1,050.82	50	21.01	9.50	690.84	48	14.38
11.30	983.00	45	21.84	10.00	691.02	39	17.71
11.40	947.47	45	21.05	10.10	779.64	47	16.58
11.50	978.63	49	19.97	10.20	617.67	44	14.03
12.00	983.02	51	19.27	10.30	716.61	46	15.57
12.10	824.71	45	18.32	10.40	571.35	43	13.28
12.20	910.00	48	18.95	10.50	650.00	32	20.31
12.30	881.14	47	18.74	11.00	650.00	35	18.57
12.40	920.64	52	17.70	11.10	695.00	37	18.78
12.50	872.04	49	17.79	11.20	629.00	32	19.65
1.00	774.24	41	18.88	11.30	620.00	38	16.32
1.10	1,041.83	47	22.16	11.40	472.03	28	16.85
1.20	936.61	48	19.51	11.50	485.80	25	19.43
1.30	832.34	45	18.49	12.00	287.05	12	23.92
1.40	963.46	51	18.89	12.10	306.51	14	21.89
1.50	823.34	49	16.80	12.20	298.42	9	33.15
2.00	898 23	45	19.95	12.30	223.69	6	37.28
2.10	863.44	49	17.62	12.40	169.13	6	28.19
2.20	1,153.48	46	25.07	12.50	172.99	2	86.49
2.30	1,048.11	39	26.87	1.00	166.00	1	166.00
2.40	882.32	46	19.18	1.10	168.03	1	168.03
2.50	1,195.30	51	23.43	1.20	155.46		
3.00	923.64	45	20.52	1.30	135.00		

19.65 average for horse-power per car without first, fourth, and last three numbers.
25.91 average for horse-power per car with first, fourth, and last three numbers.

DISCUSSION.

Mr. Geo. H. Barrus.—The results of the tests on the triple-expansion engines here reported are at variance with other data which have been obtained from similar engines. In the paper by Professor Denton which has just been read, engines of one of the types tested are shown to be capable of giving an economy represented by a consumption of not over 13 lbs. of feed water per I.H.P. per hour. Engines of the very same make and service, referred to in the discussion on that paper, have been found to use but little over 12 lbs. of feed water, and some engines used for pumping have shown less than 12 lbs. The engines tested at Minneapolis gave an economy rate of 19.05 lbs. per I.H.P. per hour. Here is an excess of more than 50% above what may be considered standard economy. Is this excess due to unusual conditions or operation of the plant, or are the results given erroneous?

Two sets of engines were tried; one at Minneapolis and one at St. Paul. In one the load was about two-thirds of the rated capacity of the engine; in the other about one-half of the capacity. In one the M.E.P. (figured roughly from the sample diagrams which are given in the paper) is 28.4 lbs. high-pressure cylinder, with 8.1 lbs. intermediate cylinder, and there is but little loop on the diagrams; while in the other it is only 7.8 lbs. high-pressure cylinder and 5.8 lbs. intermediate cylinder, and the loops on the diagrams are so marked that at one end of the high-pressure cylinder the M.E.P. is practically zero. Yet, in spite of these widely different conditions as to load, the economy of the two engines appears to be practically identical, the feed-water consumption in one being 19.05 lbs., and in the other 19.00 lbs. The authors have had opportunity, no doubt, of judging as to the reasons for this close agreement under the circumstances, although, to a critic of the paper, such agreement appears well nigh impossible.

The efficiency of the jackets on the St. Paul engine was tried with the following result: A consumption of 19 lbs. of water was required, when the jackets were in operation, to do the work performed by 16 lbs. of water when the jackets were shut off; thus showing the astonishing fact that a saving of 15.8% was made by dispensing with the jackets. This will be a tempting morsel for those who oppose the use of jacketed engines; but to myself, who

think that jackets have some virtue, it is too bitter a pill to swallow. It is stated that the steam used by the jackets when these were in operation amounted to 13.4% of the total consumption. The tests, then, would appear to show that not only the whole of this was saved by shutting off, but some two per cent. in addition was saved. In other words, there is no advantage to be gained by keeping the cylinders heated, though the heat required for this purpose is derived from an outside source. A cold cylinder is better than a hot one for the economical use of steam. It will be interesting to know how the authors account for the evident benefit derived from the jackets which is revealed in the combined diagrams which they submit on pages 1105 and 1106 of the paper, where the increased work performed by the intermediate cylinder is apparent at a glance.

The two tests, with and without jackets, are in no way fit for comparison, whether correct or not. In one the load was some 846 H.P., while in the other it was 1,018 H.P. No reliable comparison could be instituted here with so great a change in the important variable of *load*, and notably so in view of the fact that the load is, at best, exceedingly light.

I have made a careful study of this paper, and I can find no authority for the statement, given on page 1087, that on the test of the Minneapolis engine a proper deduction is made for the steam used in atomizing the oil injected into the furnaces. On page 1097 deductions are made for everything except the atomizers, but nothing given on this page, nor on pages 1121 and 1122, where the complete log of data is reproduced, makes mention of any deductions for atomizers. As I understand the record, no determination was made of the steam thus used on the Minneapolis plant of triple engines; but the quantity was determined on the Westinghouse plant, and it was found that the steam consumed in atomizing the oil amounted to 13.4% of the whole quantity consumed. If this proportionate quantity was used on the other plant, the actual weight of steam consumed by the engine is not 19.05 lbs. per I.H.P. per hour, as given in the paper and referred to here in my remarks, but 19.05 less 13.4%—that is, 16.5 lbs. I shall be glad if it can be shown that the error is mine, and that in reading the paper some point has escaped my notice which makes the record as reported correct. Should it appear that the economy of the Minneapolis engines is represented by 16.4 lbs. instead of 19.05 lbs., the relative economy of the two engines at

Minneapolis and St. Paul would then be more consistent with the observed practice with which I am familiar.

I would like to ask the authors the following questions:

(1) What is the occasion of their preference for the expression "tri-cylinder" engine, which they use in place of the common term, "triple-expansion" engine?

(2) What is the object of expressing the performance of the engine in terms of "water from and at 212°"? It is not boiler performance which is being reported, but weight of steam consumed, and it has not heretofore been thought that this weight is affected by the temperature of the feed water.

(3) What is the proportion of feed water accounted for by the indicator diagrams for the various cylinders?

(4) What is the cause of the wide difference in the initial pressures at the two ends of the high-pressure cylinder shown on Fig. 396? On the same plate, what is the reason for the wide difference in the back pressure at the two ends of the intermediate cylinder? Finally, on the same plate, why does the vacuum in the low-pressure cylinder appear to be 14 lbs. at one end and only 8.75 lbs. at the other end—one a remarkably good showing and the other unusually bad?

(5) What is the explanation regarding the apparently wide fluctuations of speed in the case of the triple engines as reported in Tables IX. and X.? Are the differences there laid down clerical errors, or did the speed actually fluctuate over the wide ranges stated?

There is so much evidence of a method different from that to which I am accustomed in the taking of the data and in the presentation of the results given in this paper, that I am forced to make my inquiries in detail, lest the conclusion be reached that the data are unreliable, and the data cannot be impugned without carrying with them the authors' conclusions.

Mr. George I. Rockwood.—These very complete tests of the St. Paul and Minneapolis Railway power plants are interesting and instructive, and thanks are certainly due to Messrs. Pike and Hugo for this presentation of data concerning the cost of motive power as furnished by these engines; for such data are rare, and correspondingly valuable. It may not be amiss, however, to offer one or two suggestions as to the inferences which may properly be drawn from the mass of data furnished.

(1) It would be unwise to conclude at once from inspection of

the paper that, other things being equal, the compound condensing engine with cylinders of the four-valve type has no ultimate economic advantage over the high-speed, non-condensing engine, operated by a single piston valve, although this is, no doubt, substantially true of these particular engines, running under these particular conditions of valve setting and load. The error in so sweeping a conclusion would be evident from the fact that while the high-speed engine represents the best practice obtainable with that type of engine, and at no time runs under conditions inimical to its creditable performance, the low speed, on the other hand, owing to light initial and final loads and to maladjustments of valve setting, is under limitations which at all times seem to prevent it from working with the degree of economy customarily obtained with such engines. Indeed, the figures given for the steam consumption per I. H. P. per hour (viz., 19.05 lbs.) show a needless waste of heat, amounting, even under these conditions of operation, to at least 20% more than need be the case. Thus it is, under the conditions, but an inferior representative of engines of its class, and so not a standard of comparison.

(2) The proportionate quantity of oil required to drive the boiler-feed and condenser pumps is excessive, and this fact is liable to lead one still further astray in this matter of comparison of the two types of engines. The horse-power required to operate the independent condensers is stated to be about 1½% of the power of the main engines. If direct-connected air-pumps and feed-pumps had been used instead, the increased economy would have been quite 10%.

(3) But if by good engineering it is thus possible to save 30% of the steam and oil used, then it is manifestly unfair to charge against the low-speed engine, in the final cost account, the interest and depreciation on so many boilers as should be charged against the high-speed engine.

(4) If fewer boilers and engines are needed in concentrated than in subdivided power, then it does not appear why the expense for labor in the case of the former should be considered in the balance sheet as greater than in the case of the latter. It seems as if, to be fair, it should at all events be taken as less.

(5) The following table of cost per day of power derived from low-speed high-duty engines is based on the foregoing conclusions, and upon the data presented on page 1118 of the paper:

Cost of oil, at $0.0257 per gallon	$130.57
Lubricating oil and waste	4.55
Labor	16.83
Superintendence	2 75
Cost per car mile, for fuel oil, labor, lubricating oil, waste and superintendence	$0.009037
Interest on machinery (value of machinery, $98,000)	$16.15
Interest on real estate and buildings	5.59
Depreciation of machinery	26.91
Cost per car mile for interest and depreciation	$0.002842
Total cost per car mile	$0.011842

The difference between this cost per car mile and the cost for the subdivided power, as given in the table in the paper, is $0.005188, which is a 30% saving in favor of concentrated power—if, indeed, these two kinds of engines are to be taken at all as standards of comparison in the matter of concentrated power *vs.* subdivided power, both as to the size of the units employed in the two cases and as to the type; the one using a condenser, and the other exhausting through the atmosphere.

(6) Judging from the rates of increase and decrease of power, as shown by inspection of Table XXV., it would seem a better arrangement if the two large triple engines had been somewhat smaller, and a third compound engine, of from three to four hundred horse-power, had been available to run during the times when the load was light, and at other times in connection with one of the large engines; thus securing a more even adjustment of engine to load than was the case.

(7) If instead of being triple engines the intermediate cylinders were suppressed, and the steam passed directly from the small high-pressure cylinder into a large superheating receiver, and thence into the low-pressure cylinder, in accordance with the system of compounding devised by the writer, then the economy of the plant would be materially increased, as the percentage of friction would be much less, and at light loads there would be no such choking of the exhaust as is shown on the indicator diagrams taken from the first and second cylinders, which are illustrated in the paper.

Mr. Jesse M. Smith.—It seems to me that the last two speakers have entirely forgotten that these engines are driving an electrical railway plant. Such an engine is not comparable with anything else in the world except, it may be, a rolling mill engine.

In electric railway service the power varies from practically the friction of the engine to its maximum capacity within spaces of time such that cards under fixed conditions are not deducible from the indicator diagrams. For instance, on this triple-expansion engine the steam may start in at one end of the high-pressure cylinder, and before it has gotten into the condenser the load has changed more than 50%. This may account somewhat for the discrepancy in the indicator diagrams which Mr. Barrus has spoken of as being good at one end and decidedly bad at the other. The last speaker has said that it would be better if smaller engines were used. That would be true if the load were constant, or anywhere nearly constant, but in electrical railway practice it is necessary to have an engine that will make the "wheels go round"; and where the load varies from practically nothing to the maximum capacity of the generators it is necessary to have the engine large enough to do that maximum work. It follows, of course, that this cannot be an economical engine, as we usually understand economy. This will account for the wide discrepancy between 12 lbs. of water, which Mr. Barrus says can be had in good practice, and 19 lbs. of water per horse-power per hour, as recorded in the test. I consider that 19 lbs. is a good economy for electrical railway service under the conditions of this plant. In regard to the question of low-speed as compared with high-speed engines for this particular service, it must be taken into consideration that, where the loads change so rapidly and so excessively, the engines must be built specially heavy for the service, just as they are in rolling-mill service. Break-downs are common. Repairs have to be looked after, and it is a question whether the simpler engine, even with a higher consumption of steam per horse-power, is not decidedly the most economical engine for that service. Here we find that a triple-expansion engine of the highest economy, under constant load, when it is compared with a Westinghouse engine exhausting into the atmosphere, is only some two or three per cent. less in its total economy. What an object lesson! Here what by some persons has been considered a very uneconomical engine is compared with one of supposed greatest economy, and shows at the end of the total summing up that the first is really nearly as economical as the most perfect engine. Mr. Pike's paper has emphasized and brought forward the work which Mr. Charles E. Emery has done in the direction of comparing

the total cost of a 500 H.P. unit of power when using different forms of engines, and shows that "the happy mean" is decidedly the best.

Mr. Fred. A. Scheffler.—I wish to point out a few changes in horse-power as noted in Table XVI., covering the points which Mr. Smith has brought up as to extreme variation. I think if the gentlemen who presented the two written discussions had referred to this table they would unquestionably have discovered the very points brought out by Mr. Smith. For instance, at time 7:10, on test No. 2, at St. Paul, the horse-power as shown is 554. Ten minutes later the horse-power was increased to 897. Twenty minutes later it had gone back to 748. Ten minutes later it had decreased again to 647. Twenty minutes later it had jumped to 939. The paper is very complete, so far as I have been able to investigate it, with the exception of one important matter, in relation to the fact that there is no record in the latter part of the paper, where the tables are presented, referring to the fuel-oil consumption in test No. 3 at the Minneapolis station. Now, for personal satisfaction I wish to discover in regard to the boiler test the amount of fuel oil which was used. I do not find it anywhere in the paper, and I would like to ask if that could not be attached to the record before the paper is printed in our proceedings.

Mr. D. C. Jackson.—The paper by Messrs. Pike and Hugo represents a vast amount of painstaking and laborious work, and the gentlemen are deserving of much praise for bringing the matter before the congress in such complete form. Any criticism to be made cannot be upon the methods used, for they seem to have been excellent. The difficulties encountered in making such tests in large electric railway power houses, where the machinery is worked to its utmost, are seldom appreciated, and Messrs. Pike and Hugo have surmounted them admirably.

The data derived for determining the comparative value for boiler fuel of coal and petroleum are particularly valuable. While a number of experimental determinations of their comparative value are available, in nearly every case the data have been obtained in such a way as to make its application to actual operations uncertain. The records have also disagreed so thoroughly that it is a satisfaction to have placed before us the results of a thorough test, which can in any event be relied upon as representing the facts in Western cities.

The deductions to be drawn from the tests to determine the comparative merits of "concentrated and subdivided power" units are more open to question. The Minneapolis No. 1 and St. Paul power stations were equipped among the earlier of the large electric railway stations. They have great triple-expansion engines, and while the maximum load is great, the fluctuations in the power developed are equally marked for range and rapidity. The engines are working at an average load much below their normal, and, as is well-known, the ordinary triple-expansion engine is a monstrously uneconomical machine when operated much below its normal load under the conditions found in the electric railway power house. These engines are directly compared in the paper with compound engines which are specially designed for service under fluctuating loads. As an illustration of the effect of ordinary electric railway loads upon the economy of compound engines not specially selected for the service, I will cite a case which lately fell under my observation. The engine in this case is a compound condensing engine guaranteed by its makers to work under its steady rated load with a consumption of 20 lbs. of water per horse-power per hour. Tests show that its performance is not far from the guarantee. In regular electric railway service its load varies from friction up to the full load, the average being about four-tenths of its rating. Under these conditions it consumes 35 lbs. of water per horse-power per hour, and a simple engine on such a plant would probably be more economical. Experience with many similar plants seems to point out that higher economy would be reached in the Minneapolis and St. Paul stations were the great triple engines replaced by properly designed large compound engines. This being the case, the advantage is not on the side of the extreme subdivision of power at the second Minneapolis station. The advantage of a limited subdivision, which enables the dynamos and engines to be kept at the greatest practicable average load, seems evident; but in large stations, such as those under consideration, this is cared for by dividing the power into not exceeding five direct-belted or direct-connected units. It is to be hoped that the results from such a station, using properly designed compound engines, can soon be added for comparison with the figures of Messrs. Pike and Hugo.

The experience of Messrs. Pike and Hugo, showing that the

loss by friction is not correctly given by diagrams plotted from indicator readings and electrical readings (page 1102 of paper), is quite a common one where the engines are much underloaded, even where high-speed engines are used. Doubtless the explanation given in the paper partially covers the facts, but the difficulty of making all readings exactly simultaneous gives an added reason where the load is very variable.

Finally, I wish to again congratulate the authors for the very satisfactory results which they have obtained in these most difficult tests, and to specially thank them for the excellent diagrams representing the movements of cars and the passengers carried.

Mr. W. D. Ball.—I beg to call attention to a matter, of perhaps small importance, in connection with the paper on the performance of street railway power plants, read before the recent meeting of the Society at Chicago. I refer to the method of measuring the actual mean power supplied by the engines. The writers based all their calculations for water and coal consumption upon the power as found by indicator cards taken every ten minutes. To be sure, they took ammeter readings every fifteen seconds, but they do not appear to have used them except as a sort of interesting fact in regard to the electrical horse-power.

As brought out in the discussion, the power may vary many times a second, from which it can be readily seen what are the chances of getting an accurate measure of the mean power from cards taken once in ten minutes. It is only a question of what we are willing to call accuracy, but it does not seem to me that engineers can afford to leave so much in the hands of chance. Although apparently a small matter, yet it is in a position where it can tip the beam either way, as it were, and certainly ought not to be passed over without comment, as it was passed both in the paper and the discussion.

It would seem that in a test of such scope there should have been some method of checking up the horse-power as found from the indicator cards, especially as such a simple method could have been adopted. Two, or perhaps three, wattmeters might have been placed in circuit by which the total power consumed during the run would have been recorded in watt-hours. The wattmeters could have been calibrated in a ten- or twelve-hour run by comparison with a correct voltmeter and ammeter on a practically steady current. Then, as both voltmeter and am-

meter readings were taken simultaneously with indicator cards, there would have been plenty of data for reducing the electrical to the indicated horse-power. There would then be obtained a correct measure of the horse-power hours, subject only to errors of observation. As to the extra expense of the test, that is not to be considered, as every well-regulated railway power plant ought to have wattmeters constantly in circuit if they want to ascertain the actual economy of their plant as compared with good practice.

Mr. F. M. Rites.—In the criticism of the results given in this paper the fact seems to be lost sight of that these were not tests for the purpose of obtaining the greatest possible economy of the steam plant in each case, but rather intended to give some record of how far from the best results possible under good conditions these plants will depart when under the conditions of railroad service. There should be no reasonable doubt that the engines in all these plants could accomplish as low water rates as elsewhere, under similar conditions ; but it is the difference of conditions in uniformity of load and division of power that makes all the difference of results.

Looked at in this light, the water rates in all cases seem to me to be unusually low ; and a possible explanation is that in a plant of such a magnitude the load is comparatively uniform and the immense losses from continuously varying loads reduced to a very low amount. Considering this, a more natural question would be, If, in such a pretentious plant, the waste from irregular concentrated power is so great on an average, what must it be on occasions of lightest load ? Or, better still, if the economy of a plant of such a magnitude falls off so rapidly with so moderately variable loads, what must be the case of the railway plant of the average size where the load is constantly fluctuating between extremes ? The authors of the paper deserve great credit for the care they have taken to collect and arrange the data and results ; but its best value is as an indication of how much depends on an intelligent design of the railway power plant.

Mr. T. W. Hugo.—I think the gentlemen in discussing this paper should bear in mind the ground covered. There is no question but that errors may creep in ; but the paper endeavors to cover a great deal of ground, and, necessarily much has to be omitted that possibly would be interesting to each and all.

Replying to a few of the criticisms which have been made: In regard to Mr. Rockwood's paper, in which he stated that the horse-power necessary to operate the condensing apparatus was 1½% of the power of the main engines, he says that if direct-connected air-pumps were used a saving of 10% would ensue. Ten per cent. of what? It surely cannot be 10% where there is only 1½% existing. He might mean 10% of the steam required by the condensing apparatus used, over that required if the air-pump was directly connected to the engine; but this certainly cannot mean 10% of the total steam consumption of the main engines. Then he goes on to say, in the paragraph before that, that because the engine was not properly suited to its work there was a loss of 20%, and he adds the 20% just spoken of, and the 10% which he claims would be gained by using a direct-connected air-pump, making 30%. So it seems to me that he is considerably in error there. To another paragraph, I would reply that the expense for labor is less, because it is less—because not so much is required. The one engineer in the Thirty-first Street station can do the work of four men in either St. Paul or in the Hill station at Minneapolis. The reason why the labor item is small is because it is small. He formulates a table of cost based on this 30% reduction, which may be correct, but was not what we found. It may possibly be stated that the final comparison per car mile as given in the paper is made by bringing both plants as nearly as possible to some point of comparison. For instance, it was found impossible to separate the heat required for heating the building and atomizing the oil from the heat of the steam consumption of the Minneapolis engine. To eliminate that, we took the steam consumption of the St. Paul engine and applied it to the Minneapolis engine. Now, in the Thirty-first Street station—that is, where the Westinghouse engines are used—the mileage is increased, so that we had a certain number of miles and a certain number of horse-power, using data that is given here and is shown by the tables, and being, as we believe, correct. That is the only assumption that was made. In regard to the extreme differences of opinion between Mr. Barrus and those given in the paper, Mr. Jesse M. Smith has very ably explained that. The engine Mr. Barrus speaks of was not the kind of engine that was being tested. It was another kind of engine, under widely different conditions, and not at all under theoretical conditions. I

would like also to call attention to the difference between the results at St. Paul and Minneapolis being so small, and that was to bear in mind that the atomizing of the fuel oil was counted in on the Minneapolis engine. So that you will understand that, although they agree pretty well, the one engine was not as economical as the other, and that explains why. Also, in regard to his criticism on the cost of atomizing the oil, the reduction was made, if not directly stated in each case, except in the case as above.

Mr. Aldrich.—Table XVI. cannot possibly show at all the great variations in the horse-power. The question of cable plant, which I had in hand at one time, was treated of by endeavoring to get the power required to run the cable cars, and also the power required to operate the transmission machinery.

And that leads me to consider the remarkable statement made in this paper, in regard to friction and loss, on page 1102. In testing the electrical railroad in 1891, we found that it was impossible to arrive at any satisfactory conclusion as to what became of the power, shutting off and on again as quickly as it was done in the power of an electrical railroad, and we found that sometimes there was as much as 40 H.P. unaccounted for. All at once, while the turbines were going down, perhaps 50 or 60 H.P. were thrown off, and they would keep on closing while this horse-power was being thrown off. At other times the power was run enormously high. There would be perhaps 60 or 70 horse-power more than was required for all the transmission machinery and for all the motors on the line. You cannot see between these two extremes, excessive power on the one hand and excessive deficiency of power on the other. There must be some cause, not only for the turbine balance, but for these extreme points, which will explain that. The writers of the paper take the ground that the power required for the steam accounts for this irregularity of power. Now, in writing our report on these turbine tests, we took the ground that a steam engine ought to be able to regulate itself more closely. Steam engines are supposed to be quite accurate. Now, I think it is a very important point to bear in mind that a high-speed automatic engine in an electrical power plant, where the load is varying so rapidly, meets those changes of load with an almost equal economy. If we take the two typical papers

presented at this meeting—the Laketon test of power pumping machinery, in which the load is quite regular, and this test, in which the loads are greatly irregular—you will find much food for thought.

The main point which I wished to bring up in this connection is that the high-speed automatic engine meets the very great variations in electrical power plants, whereas the well-made Corliss engine seems best adapted to steady loads.

Mr. Carleton W. Nason.—May I be permitted, Mr. Chairman, to ask the cause of the apparent discrepancy in the figures which appear on page 1098, lines 4 and 5 from the bottom, and which, if I read them correctly, appear to be erroneous?

In the first of these lines, it appears that when the boilers are fed with water, which it is previously stated is at a temperature of 123.4°, the pounds of steam per horse-power per hour are 19. In the line following, in which correction is made for feeding at 212°, the pounds of steam used per hour are stated to be 23.

The query naturally suggests itself as to why a greater number of pounds of steam should be used per horse-power when the temperature of the feed water is higher than when lower.

The same discrepancy appears also in another table where the larger amount of steam is necessary per horse-power per hour with the temperature of the feed water at the higher point.

*Messrs. Wm. A. Pike and T. W. Hugo.**—It appears to the writers that some of the critics of this paper have entirely misunderstood its object. The tests were made, at Mr. Lowry's instance, to ascertain, not what the plants could do under ideal conditions, but what they were actually doing in everyday practice, and we were instructed to have the engines and boilers run as usual, which was done. After the official reports were handed in, it was thought that the facts obtained would be of interest and value to the Society, and hence the paper was written, with no desire to favor or disfavor anybody.

In reply to Mr. Barrus' first comparison between these results and those given in Professor Denton's paper, it would appear that no proper comparison can be made, as the conditions are so entirely different. The excess in water consumption was due to the *usual* conditions and operation of the plants. Mr. Barrus'

*Authors' Closure, under the Rules.

criticism as to the water consumption of the Minneapolis engines is on its face just, and the figures on p. 1098, giving water consumption, should be stated to include atomizing the oil, and it will now appear so corrected; *but* in all calculations and comparisons the proper corrections are made, and this amount is not in any case brought in twice. (See pages 1099, 1114, and 1115.) This was simply an oversight, but one not carried farther.

This explanation also covers Mr. Barrus' criticism as to the coincidence between the Minneapolis and St. Paul results. It may be said with reference to the remarks on the effect of the jackets, that special attention is called on the bottom of p. 1110 and top of p. 1111 to the conditions, and that the writers only claimed that the indications were that under the conditions then existing the jackets were of no value.

Mr. Barrus then asks five questions, which are answered as follows:

(1) The writers were and are of the opinion that the expressions "two-cylinder" and "tri-cylinder" better express the facts than the terms "compound" and "triple expansion"; as compound applies as well to one as the other, and triple expansion may mean three expansions or thirty.

(2) These tests were combined boiler and engine tests, and not engine tests alone, as Mr. Barrus seems to think; and as the object was to get at the cost per horse-power, etc., as run, the amount of water per horse-power was reduced to "from and at 212°," as the evaporation per pound of oil had the same basis. Farther than this, is it not a fact that giving the water consumption without at least stating the steam pressure does not provide means of comparing different engines at different pressures?

(3) Obtaining the proportion of feed water accounted for by the indicator diagrams was one of a number of things not attempted.

(4) As far as the diagrams need accounting for, Mr. Jesse M. Smith has amply covered the ground.

(5) The fluctuations in speed, shown in Tables IX. and X., may be accounted for by the fact that the observer taking them also took the readings of steam and vacuum gauges, and though he took them always in consecutive order, yet there may have been slight variations in time between readings of the counters; but as the totals and averages are only used, the results are not affected.

Mr. Jesse M. Smith's remarks need no reply, as he at least appears to appreciate the difference between a test of a street railway and that of a pumping plant.

Mr. D. C. Jackson considers that the deductions as to the comparative merits of concentrated and subdivided power may be open to question, but it should be borne in mind that the writers have only attempted to draw a comparison between these particular plants, and express no opinion as to whether either is the best that can be devised.

Mr. W. D. Ball's criticism to the effect that wattmeters or other means might have been used, is answered only by stating that doubtless many other things might have been done; but the tests as carried out were on a sufficiently large scale, and more was not attempted.

It should be said, however, that the results as to cost per car mile are not affected by the accuracy of the figures giving horse-power, as the same results would have been obtained if no such data had been observed.

Mr. Carleton W. Nason asks about the reductions of steam to "from and at 212°." He evidently does not understand what is meant, which was to obtain the amount of steam that the heat used to evaporate say nineteen pounds of water under existing conditions would have produced if evaporated at 212° from water at the same temperature, which would give more than the original nineteen.

Finally, as to the conclusions reached. They are obtained from figures fully set forth in the paper, and while they can doubtless be combined in different ways (as, for example, taking the St. Paul mileage, and computing the expense per car mile for that), any one desiring to do this has the figures at hand. It was not thought best to farther extend the paper.

DXLVII.*

THE DEVELOPMENT OF THE COMPOUND LOCOMOTIVE.

BY A. VON BORRIES, OF HANNOVER, GERMANY.

[NOTE.—The historical part of this paper including the time prior to 1875 is founded on Mr. E. Bruckmann's communications published in the *Organ für die Fortschritte des Eisenbahnwesens*, 1890, page 294; and 1891, page 192.]

THE greatly extended application of the compound principle to locomotive engines within the last ten years, and the large number of different devices which have been introduced by inventors and builders, make it desirable to point out what had been done in compounding locomotives before they were brought into actual service, and what are the principal features of the various compound systems now in use. In this way it will also be possible to determine which of the various applications should be regarded as "systems" and which are only applications of the same system in a different manner.

The first attempts to economize the use of the steam in locomotives by multiple expansion were made at an early date, and the majority were based upon the application of the principle of the Woolf steam-engine to locomotives.

The earliest invention in this direction was by Mr. Roentgen, a Dutch engineer, who, in February, 1834, took out English and French patents for a "machine à vapeur expansive à cylindres independants et combinés." In his specification Mr. Roentgen proposes to overcome the difficulties of the Woolf engine by arranging the two pistons in such a manner that one is in the middle of its stroke when the other is at the end. The steam passes from the small to the large cylinder through an intermediate reservoir placed between the cylinders so as to get a more equal motion, and to prevent shocks. This reservoir may be placed in the smoke-box in order to utilize the heat of the gases for increasing the temperature and pressure of the steam. The invention is claimed as applicable to marine

* Presented at the Chicago Meeting (July, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

engines, but the inventor expects the same advantages from its application to locomotives. From this extract from Mr. Roentgen's specification it will be seen that his engine is the first two-cylinder "compound" engine; *i.e.*, multiple expansion engine with two separate cranks set at an angle of 90° and with an intermediate receiver.

It will also be seen that Mr. Roentgen had perfectly understood the working conditions of his engine. Probably he did not succeed in introducing his engine because there was not at that time any obvious necessity to improve the economy of marine and locomotive engines.

Another early invention which relates to the compound locomotive was introduced by Mr. John Nicholson, foreman on the Eastern Counties Railway, at Norwich, in 1847.* In Nicholson's engine there are two cylinders with cranks set at 90°. The steam enters the first cylinder during nearly one-half of the stroke, then by special gear a communication is opened with the second cylinder in which the piston is at the end of its stroke, and expansion begins in both cylinders. Shortly after the communication is closed again, the expansion continues separately in both cylinders. In the first cylinder the end-pressure is somewhat high, for the purpose of causing a strong blast. In the second cylinder expansion is utilized as much as possible. For the purpose of starting, live steam is admitted to the second cylinder by a suitable arrangement. This engine, which the inventor called a "continuous expansion" engine, works as a compound only for that part of the steam which is expanded into the second cylinder. It might better be called a "semi-compound" engine.

In February, 1860, Mr. Ebenezer Kemp, of Dundee, invented a special arrangement of cylinders for working the steam on the Woolf principle. The low-pressure piston is set on a long plunger working on both sides in suitable smaller cylinders fixed on the covers of the low-pressure cylinder. This pair of small cylinders represent one high-pressure cylinder. The steam is distributed by one slide-valve in a similar manner to the Woolf engine. For locomotives each crank is driven by one set of cylinders. This scheme was worked out by Mr. William Kemp, chief draughtsman of the Glasgow & South Western

* English patents of April 5, 1850, No. 13,029, and September 8, 1868, No. 2,769.

Railway, but the locomotive superintendent refused to try it. Mr. Kemp's engine contains all the essential features of the tandem arrangement afterward introduced on a number of railways.

In 1866 M. Jules Morandieres, then engineer of the Chemin de Fer du Nord (France), published a design for a three-cylinder compound locomotive for the Metropolitan Railway (London).* This engine has four driving axles divided into two independent groups, the two axles of each group being coupled by outside rods. One group is driven by one inside high-pressure cylinder, the other by two outside low-pressure cylinders, all of equal diameter and stroke. For starting, all cylinders can be worked with live steam. (This project has not been executed.) Mr. Morandieres' invention was not entirely new, because in George Stephenson's English patent dated August 10, 1846, No. 11,086, relating to locomotives with three high-pressure cylinders, the possibility of working this engine on the "Woolf" principle is mentioned. Morandieres' system was afterward tried in 1879 by the Struve Locomotive Works, Kolomna, Russia; and in 1887 by the Chemin de Fer du Nord, France. The latter engine was exhibited at the Paris Exposition in 1889. Mr. F. W. Webb's system of three-cylinder compound locomotives may also be regarded as a modification of Morandieres' engine.

Mr. William Dawes, of Kingston Grove, Leeds, England, proposed in his patent specification of June 20, 1872, No. 1,857, to expand the steam in locomotives into two pairs of cylinders, the two high-pressure cylinders driving one axle and the two low-pressure cylinders the other axle. The axles were not coupled, thus doing away with side-rods. In another scheme, all four cylinders work on the same driving axle, the two inside high-pressure cylinders on two inside cranks, and the two outside low-pressure cylinders on the outside crank-pins. For the purpose of starting, Mr. Dawes proposes to conduct live steam into the receiver by a suitable slide-valve, connected with the link-motion lever in such manner that it admits live steam to the receiver when the lever is in full-gear position. Dawes's specification contains some other modifications, with coupling chains and oscillating cylinders. In 1884 a locomotive on the Scinde, Punjab & Delhi Railway (India) was compounded in a

* *Engineering*, November 23, 1866.

similar manner to Dawes's proposition.* Dawes's invention was the last of those relating to compound locomotives which have not been successfully introduced in practice, and it may, therefore, be said that with this the first development of the compound locomotive ceases.

Mr. A. Mallet, engineer, Paris, has been engaged since 1874 in adapting the compound system to locomotives. The first description of his engine was published in the *Revue Industrielle* of October 25, 1875. This description refers to an engine with two cylinders of different diameters working on cranks set at an angle of 90° to each other.

For starting and attaining a maximum tractive force on steep gradients with such moderate diameters of cylinders as would give the most economical result, Mr. Mallet proposes to work the locomotive either as a compound engine, or with live steam and free exhaust in both cylinders as an ordinary engine, at the will of the driver.

For this purpose he uses a special converting or change valve mounted on the smoke-box and worked by a screw from the cab. This valve is connected with both cylinders and with the live and exhaust steam-pipes in such a manner that when in one position the steam from the high-pressure cylinder is conducted to the low-pressure cylinder, the direct exhaust from the high-pressure cylinder and the live steam to the low-pressure cylinder being cut off, the engine thus working compound. In the other position the valve opens ports admitting live steam to the low-pressure cylinder and direct exhaust from the high-pressure cylinder, and closes the communication between the two cylinders, the engine thus working with live steam and free exhaust to both cylinders as an ordinary engine.

The original Mallet system, as described, is to be classed as a two-cylinder locomotive which may be worked either as a compound or as an ordinary engine.

The special feature in the Mallet system consists in the manner of working the engine with only two cylinders of different diameters, the application of this manner of working to a three-cylinder engine having been already proposed by R. Stephenson and Jules Morandieres.

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* Institute Mechanical Engineers' *Proceedings*, 1886, page 356.

The first engines on Mallet's system were built in 1875 at the Creusot Works for the Bayonne & Biarritz Railway, and were the first real compound locomotives which proved successful in ordinary service, so that Mr. Mallet has the credit of having really introduced the first compound locomotives.

In the following years some engines for French, Austrian, and Russian railways were built or transformed on the Mallet compound system, but, notwithstanding that the engines proved more economical than those of ordinary type, they were not generally introduced by the railways, probably because they were still not simple enough in construction and handling.

The first engines had double handles for the reversing gear, which could be coupled together for shunting, but had to be worked separately when running. The economical working of the engines thus depended upon the intelligence of the driver. In 1884 Mr. Mallet introduced a slide mechanism to avoid this double handling, and to get the proper proportion of cut-off in both cylinders automatically. In the first engines constructed for the Bayonne & Biarritz Railway, the low-pressure piston received the full steam pressure when working non-compound, thus giving very unequal tractive force and causing the train to shake at slow speeds. Mr. Mallet remedied this by putting a reducing valve in the change valve casing for the purpose of reducing the steam pressure for the low-pressure piston in proportion to its larger area and thus securing nearly equal working of both pistons, but this added another moving part to the engines. As the change valve was subject to the full steam pressure it was very difficult to change the motion after starting. To obviate this, Mr. Mallet in 1884 introduced a double valve governed by a piston, which was easily worked by a three-way cock from the cab.

For the purpose of constructing powerful goods engines, Mr. Mallet proposed in 1879 a four-cylinder arrangement, the high-pressure cylinders being fixed on the front covers of the low-pressure cylinders. In another scheme he proposed to replace the low-pressure cylinder by two cylinders in one casting and worked by one slide-valve.

In 1880 Mr. von Borries, then engineer of the Prussian State Railway at Hannover, encouraged by the economical results of

Mallet's locomotives, proposed * to simplify the construction and handling of the two-cylinder compound locomotive by only using live steam in the low-pressure cylinder for starting and one handle for the reversing gear, the proper proportions of cut-off in both cylinders being made by the gear itself.

The first locomotives on this system were two small omnibus engines, built at the works of F. Schichau, Elbing. For starting they have a small port in the face of the regulator, which is opened and passes live steam into the receiver when the regulator is full open. The link motion is of the ordinary kind, giving equal cut-off in both cylinders.

This arrangement not being fitted for larger engines, Mr. von Borries proposed to admit live steam of reduced pressure into the receiver through ports in the double regulator valves and faces, which could admit steam when the small regulator valve is open. For the same purpose he also patented a slide-valve † coupled to the reversing gear in such a manner as to open a small communication between the high-pressure steam-pipe and the receiver when the engine is in full gear. A similar arrangement was previously proposed by William Dawes, and was afterward used by Mr. G. Lindner in the form of a two-way cock.

Instead of this arrangement Mr. von Borries supplied two goods locomotives built in 1882 with small reducing valves, which on starting filled the receiver with steam of 40% of the boiler pressure, and which could be closed by the driver after starting. The back-pressure which is exerted on the high-pressure piston by the steam in the receiver when the slide-valve happens to cover the steam-port was overcome in these engines by a small check-valve which, when necessary, permitted steam from the receiver to fill up the space behind the high-pressure piston.

On these engines Mr. von Borries also applied the differential reversing gear, which gives to both cylinders automatically the proper proportions of cut-off in the simplest manner, by setting the lifting levers on the reversing shaft at a certain angle and making the lifting links of suitable different length.‡

By these means the two links are hung in such different posi-

* *Organ für die Fortschritte des Eisenbahnwesens*, 1880, page 228.

† German patent, December 11, 1880, No. 14,176.

‡ *Organ*, 1883, page 147.

tions that for 40% cut-off in the high-pressure cylinder 50% in low-pressure cylinder is reached for running forward, which proportion was found the best. For back-gear, only the full-gear notch is to be used.

The latter defect was overcome in 1889 by a slide-link arrangement, invented by M. Kuhn, engineer to Henschel & Son's Locomotive Works, Cassel, which gives the proper proportion of cut-off both forward and backward in a similar, but simpler manner than by Mr. Mallet's method.

After some years' experience with these two goods engines, and with ten larger omnibus and four express locomotives, Mr. von Borries became convinced that it was not possible to get the necessary starting power by filling up the receiver, but that the full steam pressure on the high-pressure piston and a suitable reduced pressure on the low-pressure piston was needed to start fully loaded goods trains on grades, and short-coupled passenger trains at stations, without delays. He therefore introduced, in 1884, his well-known intercepting valve,* which, when closed by the driver, separates the low-pressure cylinder from the receiver, and opens a small communication with the main steam-pipe. When the regulator is then opened, the wire-drawn steam which starts the low-pressure piston cannot enter the receiver and induce back-pressure on the high-pressure piston. After starting, the receiver is filled by the steam exhausted from the high-pressure cylinder to the same pressure as in the low-pressure valve-chest, and the intercepting valve opens automatically, shutting off the live steam, the engine then working on the compound principle.

At the same time, Mr. T. W. Worsdell, then locomotive superintendent of the Great Eastern Railway (England), introduced a similar arrangement, in which a flap intercepting valve is closed when starting, by the live steam for the low-pressure cylinder working on a small piston. This steam is governed by a small valve from the cab, and shut off when the train is in motion.

A similar arrangement was afterward made by Mr. Busse, locomotive superintendent of the Danish State Railway.

In 1887 Mr. von Borries added to his intercepting valve one or two small pistons, or an annular face on the rod, which were ex-

* German patent, October 23, 1884, No. 31,340.

posed to the live steam, and closed the valve automatically when starting.* By this means the action of the intercepting valve became fully automatic.

The Worsdell and von Borries system, as now applied to some 1,650 compound locomotives in all parts of the world, means a two-cylinder compound engine which starts with live steam in both cylinders, and begins automatically to work as a compound when the receiver has been filled by the exhaust from the high-pressure cylinder. In this system only one handle is necessary for the reversing gear, the proper proportion of cut-off in both cylinders being regulated by the different positions of the levers on reversing shaft and different lengths of hanging links.

It has been questioned if the Worsdell's von Borries system really deserves to be classed as a "system" proper, or if it is not only a modification of Mr. Mallet's system.

From the facts stated above, it will be clear that Roentgen was the first inventor who had proposed to work a two-cylinder locomotive on the compound principle, and that, as is well known, many stationary and marine compound engines with only two cylinders were at work before 1875. Therefore, a two-cylinder compound locomotive cannot be classed as Mallet's or another inventor's system, but is only the application of well-known principles to a locomotive. Also, as stated before, the Mallet system is characterized by the possibility of working the two-cylinder locomotive either as a compound or as a single expansion engine at the will of the driver. The Worsdell's von Borries system is characterized by only starting with live steam in both cylinders, and automatically changing to compound working shortly after starting. Both systems differ in the most essential point, and, therefore, the latter deserves to be properly called a "system." By this statement, the credit due to Mr. Mallet for having first successfully applied the compound system to locomotives is not touched.

All the numerous arrangements of the two-cylinder compound locomotives, which have been introduced since 1885, are worked on one of these two original systems, and therefore are only modifications of them.

The Mallet system was altered by Mr. Borodine, engineer-in-

* German patent, September 7, 1887, No. 43,178.

chief of the South-Western Railway of Russia, who applied a cylindrical change-valve; and by Mr. Middelberg, engineer-in-chief of the Dutch Railway, who made the low-pressure cylinder of the same diameter, but double the stroke of the high-pressure cylinder. Another modification was invented in 1891 by Mr. Aspinall,* locomotive superintendent of the Lancashire & Yorkshire Railway (England), who applied a large cylindrical four-way cock in combination with a small live-steam valve, to work the engine both simple and compound.

In 1892 Mr. von Borries introduced his double piston change-valve,† in which the two pistons work as a reducing valve for the live steam passing to the low-pressure cylinder.

Mr. Herbert Lapage, London, in 1889 added to the Worsdell's von Borries system an auxiliary valve, between the high-pressure cylinder and the intercepting valve,‡ by which a direct exhaust can be opened from the high-pressure cylinder; the engine can therefore be worked either on the Mallet or Worsdell's von Borries principle. A similar arrangement was brought out in 1890 by the Rhode Island Locomotive Works, of Providence, U. S. A.,§ to which the Franklin Institute, in 1892, awarded a prize as for a new system. The Worsdell's von Borries system is also used by the Schichau Locomotive and Shipbuilding Works, Elbing, who replaced the intercepting valve by a slide-valve driven automatically by pistons, and by the Schenectady Locomotive Works, N.Y., U. S. A.,‖ who replaced it by a piston driven by suitable faces and governed by an oil brake to prevent shocks.

Mr. F. W. Dean, member of the American Society of Mechanical Engineers, Boston, U. S. A., replaced the round intercepting valve by a flap-valve, governed by a separate automatic reducing valve,¶ working on the same principle as von Borries's engines of 1882.

The Brooks Locomotive Works added to the intercepting valve a self-acting reducing appliance, to admit steam of suitable pressure to the low-pressure cylinder.

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* English patent, October 22, 1891, No. 18,157.

† German patent, April 4, 1892, No. 67,234.

‡ American patent, June 18, 1889, No. 405,569.

§ *Railroad Gazette*, 1891, page 20.

‖ *Railroad Gazette*, 1890, page 73.

¶ *Railroad Gazette*, 1892, page 882.

The Rogers Locomotive Works, Paterson, N. J., applied an arrangement very similar to Worsdell's, but with a live-steam valve controlled by the reversing gear.

Mr. Lindner,* of the Saxon State Railways, wishing to dispense with the intercepting valve for the purpose of running down grades with the reversing brake, applied a two-way cock operated by the reversing shaft, to fill automatically the receiver when the handle is put in full gear, or suitable ports in the regulator valve for the same purpose, in accordance with Dawes's and von Borries's former projects. In order to overcome the back-pressure on the high-pressure piston when the steam ports are covered, Mr. Lindner provides small ports in the high-pressure slide-valve, by which steam from the receiver fills the space behind the high-pressure piston. Later on Mr. Lindner placed the entrance of the auxiliary steam-pipe just over the low-pressure slide-valve, so that live steam can enter only when one port is open. This arrangement prevents back-pressure on the high-pressure piston when this piston has to make the start.

For the same purpose the Krauss Locomotive Works, of Munich, use a special small slide-valve, actuated by the high-pressure motion, in combination with von Borries's ports in the regulator valve.

Mr. Klose, locomotive superintendent of the Würtemberg State Railways, combined the von Borries intercepting valve with Lindner's arrangement.

It is possible that other modifications of the Worsdell's von Borries system may exist, which have not been brought under the notice of the author.

In 1881 Mr. F. W. Webb, locomotive superintendent of the London & North-Western Railway (England), after having tried Mallet's system, introduced his well-known three-cylinder compound express locomotives. Contrary to Morandieres' project, he uses two outside high-pressure cylinders which drive the trailing wheels, and one inside low-pressure cylinder for the driving wheels.

In the first engines live steam was admitted to the low-pressure cylinder for starting, but in the later engines both sets of cylinders can be worked with live steam and free exhaust.

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* *Organ*, 1888, page 299.

The tandem arrangement, first proposed by Ebenezer Kemp, has been tried in various forms by different railways.

Mr. Mallet in his *Mémoire* of 1877, page 958, proposes to use the four-cylinder tandem arrangement for locomotives requiring great tractive force where one low-pressure cylinder would be too large. In his communication to the Institute of Mechanical Engineers in 1879 he shows an arrangement of this kind, the high-pressure cylinders being fixed on the front covers of the low-pressure cylinders.

In 1883 the Boston & Albany Railroad tried this system on a passenger locomotive, but without success. At the Industrial Exhibition at Edinburgh in 1886 the North British Railway Co. showed a passenger engine with inside tandem cylinders, the high-pressure cylinders being fixed on the front covers of the low-pressure cylinders, the latter occupying the usual position under the smoke-box. The results seem to have been unfavorable, no more engines having been built of this type. At the Paris International Exhibition in 1889 the Chemin de Fer du Nord showed an eight-coupled goods engine with outside tandem cylinders, the high-pressure cylinders being placed behind the low-pressure cylinders. The latter had double piston rods carried over and under the high-pressure cylinder to the cross-head. Each pair of cylinders had only one slide-valve. The results seem to be favorable, since the railway company continues to build this type of engine.

Passenger engines with outside cylinders, the high-pressure in front of the low-pressure, were built by the Grafenstaden Locomotive Works for the South-Eastern Railway of Russia, and in their own workshops by the Hungarian State Railways. The results of the trials made by the latter engine seem to have been unfavorable.

In 1890 Mr. Vauclain, superintendent of the Baldwin Locomotive Works, Philadelphia, Pa., devised a new arrangement of the four-cylinder Woolf locomotive,* placing the high-pressure cylinder above or below the low-pressure cylinder, the piston rods of each pair of pistons being connected to one cross-head. The distribution of steam for each pair of cylinders is controlled by one circular valve containing four pistons with tight-

* *Railroad Gazette*, 1890, page 298 ; *Engineering News*, 1890, page 424.

ening rings. For starting, live steam can be admitted to the low-pressure pistons, by an arrangement connected with the cylinder drain cocks. Generally, the method of working in this engine does not differ from the before-mentioned four-cylinder tandem engines, but the whole arrangement differs so much from its predecessors that it deserves to be called a "system."

A similar system was introduced in 1891 by Mr. Johnston, superintendent of motive power, Mexican Central Railroad, by placing the high-pressure cylinder in the centre of the low-pressure cylinder.* The low-pressure piston is therefore annular and requires two piston-rods and two sets of packing rings.

The arrangement of working one set of drivers by a pair of high-pressure cylinders and another set by a pair of low-pressure cylinders, these two sets of drivers being coupled or not, placed in the same rigid frame or in two articulated frames, was first mentioned in Mr. Mallet's *Mémoire* of 1877, page 958, and therefore these engines should be classed under the head of Mallet's system. A similar system was patented by Mr. Lapage, of London.

The first locomotive of this type with rigid frame was an express engine built in 1885 by the Grafenstaden Works to the designs of M. de Glehn, engineer-in-chief, for the Chemin de Fer du Nord (France), each pair of cylinders driving one pair of driving wheels which were not coupled together. More powerful engines of the same type have been built for the same road, and with similar general arrangement for the Paris, Lyon & Mediterranean Railway, in both cases with coupled drivers. The latter engine was shown at the Paris Exhibition in 1889, together with an eight-wheeled goods engine of the same type in which the two sets of four driving wheels were also coupled.

The first engine of the other type with two articulated frames, of which one is fixed to the boiler and the other is movable to enable the engine to pass round sharp curves, was built in 1889 for the Decauville light railways in France. A number of similar engines were successfully used on the narrow-gauge railway at the Paris Exhibition in 1889.

Some standard-gauge locomotives of this type have been

* *Engineering News*, 1892, page 302.

built for the St. Gothard, the Swiss Central, and the Herault Railways (France), and a further number are being built for different railways.

The several systems of compounding locomotives having been described according to the authoritative information given in the foot-notes, the author would here apologize for the omission of any systems which have not come under his notice.

The number of compound locomotives of the principal systems now running may be estimated as follows:

Mallet's system	150
Worsdell—von Borries	1,650
Webb's	150
Vauclain's	200
Others	50
Total	2,200

In looking at these figures the question arises, What will be the future of the compound locomotive? The good and sometimes excellent results which compound locomotives have always given, when the principal advantages of the system have been properly applied and complicated construction avoided, prove, that for all locomotives which have to work with moderate variation of tractive force the compound locomotive is the engine of the future.

The range of variation of tractive force within which the efficiency of the compound locomotive surpasses that of the ordinary engine is not so large as is generally supposed. For unvariable compound engines (*i.e.*, engines working compound only) this range extends between the full amount and one-half of the tractive force. For engines on the Woolf principle it is still smaller. The compound locomotive will therefore be most advantageous when the tractive force is most uniform, and will give no advantage where the tractive force is very variable.

To obtain the greatest efficiency for the compound locomotive, the cylinders should be of such dimensions as to allow the engine to be worked as much as possible with the most economical cut-off, but in most cases the pistons then become too small to enable the engine to exert the full tractive force, available by the adhesion, by working compound at full gear. It is preferable, therefore, in most cases to provide for working the compound locomotive when necessary with live steam in both cylinders on Mr. Mallet's principle.

For this purpose, designs similar to those of Mr. Lapage and the Rhode Island Locomotive Works (who apply a self-acting intercepting valve in combination with an auxiliary exhaust), and the author's new change-valve, are specially suited. With such arrangements the two-cylinder compound locomotive is capable of fulfilling all the requirements of ordinary railway service, and even to a great extent meeting the requirements of variable tractive force.

In conclusion, the author is of opinion that the two-cylinder compound locomotive will be the railway motor of the future except in cases where an extra large amount of tractive force is required, and here Mr. Mallet's articulated four cylinder compound engine will successfully replace the two-cylinder locomotive.

DISCUSSION.

Mr. H. Wade Hibbard.—In an account of the first development of compound locomotives, there should be inserted some early American efforts in that direction. In 1868 the Erie Railroad furnished a 16-inch by 26-inch Hinkley outside-connected locomotive to the King Iron-Works, Buffalo, N. Y. (then known as the Shepard Iron-Works), to be compounded by them.* It was made into a four-cylinder tandem compound after designs by H. O. Perry, Edward M. Ketcham making the original plans and details. This was the first four-cylinder compound ever run. The cylinders were 11½ inches and 24 inches by 26 inches stroke, and had rocking valves operated by shifting link motion. It was not a success, being a poor steamer, because, as was said of it, "there was no exhaust." Too great expansion probably weakened the draught upon the fire

In 1877, and for a number of years before, the Worcester and Shrewsbury Railroad, in Massachusetts, a short, narrow-gauge road, had in use a two-cylinder compound steam passenger car.† The low-pressure cylinder had a diameter of 8 inches; the high-pressure, 5 inches At the will of the engineman the car could be run compound, or both cylinders could use steam direct from the boiler. A companion car had simple cylinders 6 inches in diameter. The compound was said to use only three-fourths as much fuel as the other, under like conditions of labor.

* *Railroad Gazette*, 1890, page 646.

† *Railroad Gazette*, 1877, pages 385 and 434.

In 1883 the Baldwin Locomotive Works * built a steam car from the designs of Mr. Downe, the superintendent of the motive power of steam tramways in Sydney, New South Wales. This was a four-cylinder tandem compound, having upright cylinders, piston valves, and Joy's valve gear.

COMPOUNDS BUILT BY THE RHODE ISLAND LOCOMOTIVE WORKS.†

Name of Road.	Road Number.	Shop Number.	Class.	Name of Road.	Road Number.	Shop Number.	Class.
Union Elevated	58	1,891	Forney.	Railroad Construction Co.	107	2,921	Forney.
New York, New Haven and Hartford	58	2,600	8 wheeler.	" "	108	2,922	"
				" "	109	2,923	"
Mexican Central	141	2,625	10 wheeler.	" "	110	2,924	"
" "	142	2,626	"	" "	111	2,925	"
" "	143	2,627	"	" "	112	2,926	"
" "	144	2,628	"	" "	113	2,927	"
" "	145	2,629	"	" "	114	2,928	"
" "	146	2,630	"	" "	115	2,929	"
Union Elevated	3	1,496	Forney.	Lake Street Elevated	6	2,939	"
" "	70	1,903	"	" "	7	2,940	"
Kings County	63	2,632	"	" "	8	2,941	"
Jamaica	17	2,651	10 wheeler.	" "	9	2,942	"
Minneapolis and St. Louis	55	2,783	8 wheeler.	" "	10	2,943	"
" "	68	2,784	"	Grafton and Upton	1	2,931	Mog'l F'ny.
Northern Adirondack	7	2,780	10 wheeler.	Lake Street Elevated	11	2,954	Forney.
Mexican Central	150	2,808	Bogie.	" "	12	2,955	"
" "	151	2,809	"	" "	13	2,956	"
" "	152	2,810	"	" "	14	2,957	"
Mexico, Cuernavaca and Pacific	1	2,837	10 wheeler.	" "	15	2,958	"
				" "	16	2,959	"
Mexican Northern	7	2,838	"	" "	17	2,960	"
M., St. P. & S. Ste Marie	400	2,842	Consol.	" "	18	2,961	"
" "	401	2,843	"	" "	19	2,962	"
Kings County	64	2,858	Forney.	" "	20	2,963	"
Fitchburg	254	2,877	Mogul.	" "	21	2,964	"
M., St. P. & S. Ste. Marie	402	2,878	Consol.	" "	22	2,965	"
N. Y., N. H. & Hartford	254	2,879	8 wheeler.	" "	23	2,966	"
C., Milwaukee & St. Paul	830	2,880	10 wheeler.	" "	24	2,967	"
N. Y., N. H. & Hartford	255	2,911	8 wheeler.	" "	25	2,968	"
C., Milwaukee & St. Paul	828	2,912	10 wheeler.	M., St. P. & Ste. Marie	419	2,969	Consol.
" "	829	2,913	"	" "	420	2,970	"
Railroad Construction Co.	100	2,914	Forney.	" "	421	2,971	"
" "	101	2,915	"	" "	422	2,972	"
" "	102	2,916	"	" "	423	2,973	"
" "	103	2,917	"	" "	424	2,974	"
" "	104	2,918	"	" "	425	2,975	"
" "	105	2,919	"	" "	426	2,976	"
" "	106	2,920	"	" "	427	2,977	"

Mr. John H. Cooper.—The advantages of using steam by continued or repeated expansion in more cylinders than one, for locomotive service, are becoming better known as results are obtained from trials on the road.

Mr. Von Borries' paper is a valuable contribution to the literature of this subject; it possesses more than usual interest because it is the work of a hand well practised in every detail

* *Recent Locomotives*, 1886, page 71 and Fig. 371.

† Total number, 76.

of this novel mechanism. He wisely concludes that *two cylinders are enough.*

The writer desires to call attention to a few points which have been suggested by a consideration of the paper before us, referring the reader for detail to a report on the performance of compound locomotives built by the Rhode Island Locomotive Works, of Providence, R. I., and which embody the inventions of Mr. C. H. Batchellor; also to a report on these locomotives by a committee of the Franklin Institute, of Pennsylvania, and published in the number for May, 1892, of their *Journal.*

The Franklin Institute's award to Mr. Batchellor was not made for a new system of compounding locomotives, but for improvements upon the Baxter type of compound locomotive, by which interchangeableness of simple and compound working is secured by means of novel forms of steam-diverting and pressure-equalizing valves.

Mr. Wm. Baxter, Jr., writes under date of March 25, 1891, in reference to his father's compound locomotive: "This locomotive was made about the year 1870, and the compound type of machine was used not only to insure greater economy, but also to meet the requirements of street railway service.

"The cylinders were so arranged that when the car was running on a level it would work compounded; but when it was desired to obtain more power to ascend the grade, both cylinders worked with live steam. In this way the power of the machine could be varied all the way from 5 to 20 H.P. The first machine made, in addition to having a compound engine, had a compound boiler. The high-pressure boiler was surrounded by an annular low-pressure boiler, or regenerator, and into this latter the high-pressure cylinder exhausted. In this way the back pressure on the high-pressure cylinder was maintained uniform, and at the same time all the condensed steam was regenerated, and entered the second cylinder perfectly dry."

A letter from Mr. John F. Thomas, under date of March 13, 1891, says: "The Messrs. E. Remington & Sons did build several steam cars, known as the Wm. Baxter system. The high-pressure cylinders were 5 inches by 12 inches, and the low-pressure cylinders 8 inches by 12 inches." The drawings of these engines were made by Mr. Thomas, who also supervised their construction from 1873 onward.

Figs. 398, 399, and 400 are made after careful measures taken from an existing high-pressure cylinder, which was designed by Mr. Baxter and made and used by him on the Worcester and Shrewsbury Railroad (Massachusetts) early in the '70s. Fig. 398 shows a plan of the cylinder, valve face and ports; Fig. 399, a cross-section of the cylinder through the exhaust port EE''; Fig. 400 shows a vertical section of the intercepting valve, its chest and ports.

This cylinder was 5 inches d ameter and 12 inches stroke, and was secured to the engine framing by the semi-cylindric bracket B, shown only on Fig. 399. It was provided with the usual three-ported valve face, in which II represent the steam ports to each

Fig. 400.

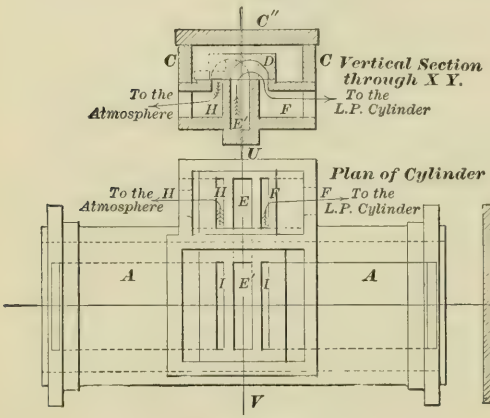

Fig 398.

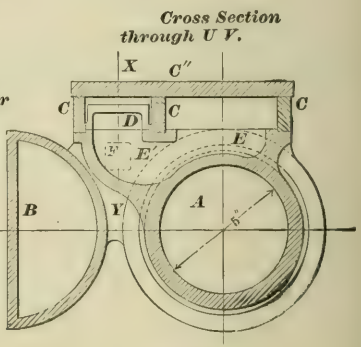

Fig. 399.

end of the cylinder, and E the exhaust port, placed between them and connecting directly to the central port E'' in the intercepting valve chest CC, which is a compartment of the main steam chest CC, placed beside it and on the same level.

Both are covered by the same lid C''; the division C' of this chest was provided with 3 openings for permitting live steam to circulate freely in both compartments.

When the intercepting valve D was placed in the position shown by the full lines, the exhaust steam from the high-pressure cylinder would flow freely through the D opening under the valve from the port E, and by way of the port F to the low-pressure steam chest, in which case the engine would work compound.

When this valve was moved to the position shown by dotted lines, the exhaust from the high-pressure cylinder would flow from the port *E* through the connected port *H* to the atmosphere; at the same time live steam would flow from the steam chest through the now uncovered port *F* to the low-pressure steam chest, in which case the engine would work as a simple one.

This valve was moved only by the engineer, and performed only the two functions named.

The low-pressure cylinder was 8 inches diameter and 12 inches stroke, and was in every particular like the cylinders of the ordinary locomotive designed for continuous simple running, its steam chest, however, being supplied with either the exhaust steam from the smaller cylinder, or with live steam directly from the boiler, according to the position of the intercepting valve *D*, as already described.

The pistons of both steam cylinders were connected to crank pins at right angles in the usual way, and the main slide valves were worked by Stephenson's link motion, such as are in common use on the locomotives of to-day.

The driving wheels were 2 feet in diameter, 4 in number, and their crank pins connected outside by solid-end side rods. The railway gauge was 3 feet. These locomotives were in regular daily service for 10 years and over.

Without disparaging the labors and inventions of other engineers who are making noteworthy efforts in the right direction, with good and substantial results, this early contribution to the development of the compound locomotive by Mr. Baxter must be regarded as not only an invention of supreme simplicity, but as one which solves most directly the problem of the two-cylinder compound locomotive.

If we add to Mr. Baxter's ready method of diverting the steam the Batchellor equalizing valve, which is another extremely simple device, being composed of a single moving piece for performing the important function of automatically maintaining equal total pressures upon unequal pistons, whatever the steam pressure may be beyond the throttle valve, we have about all the needed chief appliances for the compound and simple working of locomotives, especially when it is desired to do either kind of running and to make the change from one to the other, wholly by the will and hand of the engineer.

With these data and dates before us, including also those of Mr. von Borries' admirable paper, the case is clear that to Mr. Wm. Baxter belongs the credit of making and using continuously on the road the first two-cylinder locomotive that may be run for any length of time either simple or compound, at the will of the engineer.

Also to Mr C. H. Batchellor is due the credit of first equalizing the total pressure of the steam on each of the two pistons during simple running, whatever may be the steam-pressure after it leaves the throttle valve.

Mr. H. H. Suplee.—This communication reminds me of the fact that I had the opportunity of riding upon the identical street car which is mentioned, the date being, I think, either 1874 or 1875. This was a compound steam street car built by the Remington Arms Company, from designs of Mr. William Baxter, well known as the inventor of the Baxter engine. It was a two-cylinder compound, with cylinders under the front platform, connecting directly back to the car axle, and it was arranged so that it could be used compound, or so that both cylinders could be used at high pressure. For ordinary service, live steam was admitted to the smaller cylinder and then exhausted to the low-pressure cylinder, in the same manner as the present two-cylinder compound locomotives; but there was a valve which could be thrown over by turning a hand crank 180°, by means of which a change was made in the steam passages and both cylinders operated with live steam. This engine was in use for several weeks on the street cars of the West End Street Railway Company, of West Philadelphia, and was only removed, according to my recollection, because of the question with the city authorities about the right to use steam on street railways, and not because of any failure of its performance. The change from compound to simple was quite apparent to those riding on the cars, as the low-pressure cylinder, being of larger diameter, exerted more power than the smaller one and gave an unequal action, readily perceptible to the riders. There is no doubt in my mind that the two-cylinder compound locomotive, arranged so as to be worked either simple or compound, was in use in 1874 or 1875, and that until some prior date is discovered credit for this idea belongs to Mr. Baxter.

Mr. George Gibbs.—I would like to ask Mr. von Borries what he has had access to which would lead him to the conclusion,

stated at the bottom of his fourteenth page, that the range of economical performance of a compound is not as great as of a simple locomotive? This is contrary to my experience, although I have no conclusive data on the subject.

Mr. von Borries.—That is because of the manner in which the compound is worked. It is run up from 35% to 75%, and the range of tractive power that may be gained without throttling is a great deal smaller than that of the ordinary engine, which can be run from one-fifth to the full force. With the compound it ranges from full force down to 50% of this force. With an ordinary engine it ranges from a full force to 25%. I have sometimes found that in the winter time, when trains were light, the economy of the compounds was smaller than in the summer, with heavy trains, and I believe they have had the same experience here on the Michigan Central Railroad.

I am much indebted to Messrs. Hibbard and Suplee for the information they have given about the former application of the compound system to locomotives in the United States of America. But as these applications seem to have had no further success, they cannot be credited as successful introductions of the compound system.

DXLVIII.*

THE OPERATION OF CENTRIFUGAL MACHINES.

BY PROF. GUSTAV HERRMANN, AACHEN, GERMANY.

(Honorary Member of the Society.)

CENTRIFUGAL machines are much used in the various departments of industry, especially for the extraction of water from laundried garments, and for the separation from certain materials of those fluids which cling to them; as, for example, for the separation of the syrup from sugar crystals in the manufacture of sugar.

More recently they have been much used in the so-called covering or claying of the sugar, wherein a pure and rich sugar solution is driven through the sugar particles, whereby not only is an increase of density secured, but also an additional amount of sugar is deposited among the crystals. Moreover, by the operation of centrifugal machines, it has been essayed to clarify fluids which are turbid, and for this purpose the centrifugal basket is lined with a proper filtering material, through which the fluid to be clarified is driven, so that it leaves its impurities in the filtering material.

While it is principally necessary in this and similar processes to secure the greatest possible pressure upon the material to be operated upon, so that the process may be quick and complete, yet, on the other hand, for the separation of cream from milk in butter making, it is less necessary to secure this great pressure than to increase the difference in the specific gravity between the fatty particles of cream and that of the more watery skimmed milk.

This difference in the method of operation of centrifugal machines has not been as clearly recognized as could be desired, and there is also an uncertainty as to the way in which the pressure within the revolving basket is originated and distributed, so that often it is said, without a proper understanding,

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

that there is a pressure of three, four, or other number of atmospheres in a certain centrifugal machine. Such a problem therefore deserves a closer study of the conditions under which such a pressure may occur.

There are also certain matters in the construction of the machines themselves which have not as yet been sufficiently discussed in literature; as, for instance, the reason why centrifu gal machines so frequently work unsteadily, and the means for remedying these defects. In the revision for a new edition of the well-known work on *Engineering and Mechanics*, by Prof. J.

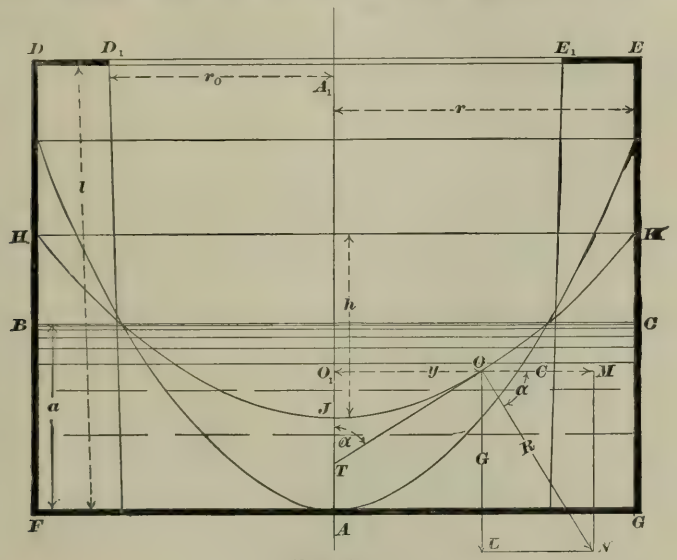

FIG. 401.

Weisbach, with which I have been concerned for a series of years, it became necessary for me to test these combinations more closely, and I feel myself much honored to present herewith certain results of my investigations, at the invitation of the American Society of Mechanical Engineers, for discussion at the World's Engineering Congress in 1893, and to place them at their disposal with the hope that they may be of interest to some of the members.

To ascertain the amount and distribution of the pressures within the drum of a centrifugal machine, let $DEGF$ in Fig. 401 illustrate a cylindrical drum in section through its vertical axis AA_1, and suppose the drum to be filled with any fluid to the

level of the plane BC. By a slow revolution of the drum on its axis AA_1 the surface of the fluid takes the well-known concave form $IIJK$, which every one has so frequently observed on a small scale when, at the table, the contents of a tea or coffee cup are set in rotary motion with a spoon. It is well known that this surface which presents itself under the influence of centrifugal force belongs to the class of paraboloids of revolution around the axis of revolution AA_1, as can easily be proved in the following manner:

If a small fluid particle, O, has a weight, G, represented by the perpendicular line $OL = G$, and the centrifugal force $C = OM$ acts horizontally outwards upon this particle, its value being given from the well-known formula of mechanics,

$$C = \frac{G}{g}\omega^2 y = \frac{G}{g}\left(\frac{n}{60}2\pi\right)^2 y = 0.01096\frac{G}{g}n^2 y,$$

in which $y = OO_1$ indicates the distance of the particle O from the axis of revolution AA_1, and n denotes the number of revolutions per minute. Let ω represent the angular velocity which gives for the tangential velocity at a unit's distance from the axis AA_1 $\omega = \frac{n2\pi}{60}$; g denotes, as usual, the acceleration due to the force of gravity, and is agreed to be 32.18 feet (9.81 m.).

The two forces G and C unite into a resultant R, represented by ON, which must place itself normal to the curve forming the surface of the fluid, from which it follows that the tangent OT to the curve JOK at the point O must form with the axis AA_1 an angle α, equal to the angle MON.

If now it be assumed that the curve JOK is drawn in such a relation to the coördinate axes that the axis of Z coincides with the axis of revolution AA_1, making the axis of Y at the lowest point J perpendicular to the axis AA_1, so that the angle of inclination of the tangent is represented by the following equation:

$$\text{tang } \alpha = \frac{MN}{OM} = \frac{G}{C} = \frac{g}{\omega^2 y},$$

it follows that

$$\text{tang } \alpha = \frac{dy}{dz} = \frac{g}{\omega^2 y}; \quad \therefore\ y dy = \frac{g}{\omega^2}dz,$$

from which is obtained by a simple integration the equation for the curve, $y^2 = \frac{2g}{\omega^2} z$. This equation shows that the curve is a parabola with its vertex at J, whose principal axis coincides with AA_1. If in this equation there be substituted for y the radius AF equal r of the drum, the vertical height h is obtained, to which the fluid has raised itself above the lowest point of the surface at the edge of the circumference of the drum at K. This height $\frac{\omega^2}{2g} r^2 = \frac{v^2}{2g}$ is just equal to the so-called height due to the velocity which belongs to a speed v at the circumference equal to ωr; in other words, the height is that reached by a stone thrown vertically upwards into the air with an initial velocity v. It is easy to see that the fluid at the circumference of the drum at K has raised itself just so far above the original plane BC as the vertex J has sunk below this plane, so that the original surface BC of the fluid bisects the height h. If, therefore, the drum be revolved at a speed so that

$$v = \omega r = \sqrt{2g2a} = 2\sqrt{ga},$$

in which a denotes the depth BF of the fluid at the beginning, the surface of the fluid will fall to the bottom line FG of the drum, and it will rise to the upper edge if the drum were filled exactly to the middle.

An increase of circumferential speed beyond this limit will result in a throwing out of the fluid over the upper edge DE, unless an annular projection DD_1E_1E be added when such result is anticipated. This additional edge is necessary with all centrifugal drums, because the angular velocity is always so great that the height corresponding to their velocity is many times greater than the height l of the drum. This can be made obvious by an example :

If the diameter of a centrifugal drum $r = 3$ feet (0.914 m.), and the height $l = 2$ feet (0.610 m.), then there would only be necessary a speed of

$$v = \sqrt{2 \times 32.18 \times 2} = 11.35 \text{ feet (3.46 m.)},$$

which speed corresponds to a number of revolutions per minute for the drum of only

$$\frac{11.35}{3\pi} 60 = 72.$$

When on the other hand, as is not unusual, the drum has a speed of a thousand revolutions in a minute, it becomes necessary to have a height due to the velocity represented by

$$h = \left(\frac{1{,}000}{60}\, 3\pi\right)^2 \frac{1}{2 \times 32.18} = 383.3 \text{ feet (117 m.)}.$$

It should be here remarked that this height is the same for all fluids, as it depends in no wise upon the specific gravity.

If the cross-section of the upper surface of the fluid be a parabola corresponding to this great velocity, provided only it falls within the centrifugal drum, it will be found that it deviates so little from a vertical straight line, that for all practical purposes it may be taken for granted that the fluid forms a cylindrical lining of equal thickness at all parts of the drum. It follows, therefore, that the greatest volume which a centrifugal drum can hold is a fixed quantity, and is given by the equation,

$$V = \pi (r^2 - r_0^2)\, l,$$

when r is the internal radius of the drum, and r_0 the radius of the circular opening at the top of the drum, and l denotes the vertical length or height of the drum.

In order now to ascertain the reasons for the pressures developed within the mass contained in the drum, it will be assumed in Fig. 402 that TT denotes the circumference of the drum, and that the contents of the drum form an annular lining against the same, with a thickness $d = r - r_0$. Conceive that this mass is divided by a great number of concentric cylindrical surfaces which, lying very near to each other, divide the mass into the same number of very thin cylindrical rings, and let $BCDE$ represent an elementary part of one of these layers whose mean radius is x, whose thickness is dx, and that it subtends a central angle α, and that its height parallel to the axis equals unity. The con-

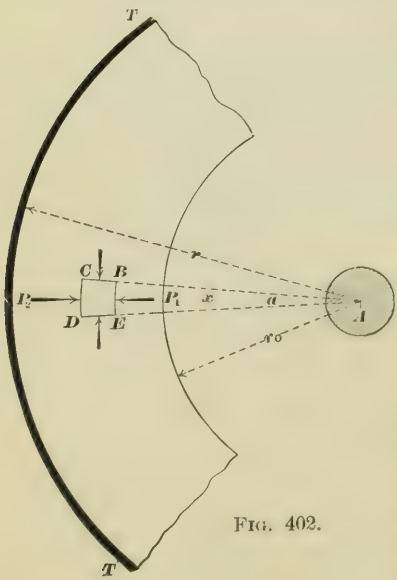

Fig. 402.

tents of this element are therefore $V = x\alpha dx$, and its weight $G = \gamma x\alpha dx$ when γ denotes the specific gravity of the mass.

On the inner surface BE of the small parallelopipedon, there is a certain pressure at work from the mass lying within, which is as yet unknown and which for each unit of surface may have the value p. Similarly, there will be on the outer surface CD a certain pressure with which the element in question acts against the mass outside of it equal to the reaction of this latter mass on the element. From B to C there will be a certain very small change in the pressure p which will be designated by dp, so that on the outer surface the pressure for each unite of area is to be considered $p + dp$. The two forces acting on the surfaces BE and CD are therefore $P_1 = px\alpha$ directed from within outwards upon BE and $P_2 = (p + dp)x\alpha$ acting from without inwards on the surface CD. To these two forces must be added the centrifugal force from the mass of the element itself whose value is

$$dC = \frac{G}{g}\omega_2 x = \frac{\gamma}{g} x\alpha dx\omega^2 x,$$

so that for the equilibrium between these three forces we must have

$$(p + dp)x\alpha = px\alpha + \frac{\gamma}{g} x\alpha dx\omega^2 x;$$

whence,

$$dp = \frac{\gamma}{g}\omega^2 x dx,$$

and by the integration of this equation we have

$$p = \int_{r_0}^{r} dp = \frac{\gamma}{g}\omega^2 \frac{r^2 - r_0^2}{2} = \frac{\gamma}{2g}\frac{n^2 4\pi^2}{3600}(r^2 - r_0^2) = \frac{G}{g}\frac{\pi n^2}{1800}.$$

In this expression $G = \gamma\pi(r^2 - r_0^2)$ denotes the weight of that mass which is contained in any height of the drum equal unity, and which, therefore, can be put $G = \frac{Q}{l}$, if Q is the weight of the entire charge of the drum and l denotes the height of the latter parallel to the axis.

It is found from the deduced formula for the pressure p, in the interior of the mass, that the pressure has not a constant value throughout the working mass, as is the case, for instance,

when one places material between two plates in a hydraulic or a screw press. In charges worked in centrifugal machines the pressure on the innermost surface is equal to nothing, but it increases gradually toward the outside, so that the greatest pressure is at the outer circumference This greatest pressure is therefore not dependent alone on the angular velocity ω of the drum and on its radius r, but also greatly on the weight of the matter itself. This pressure would be at a maximum if the

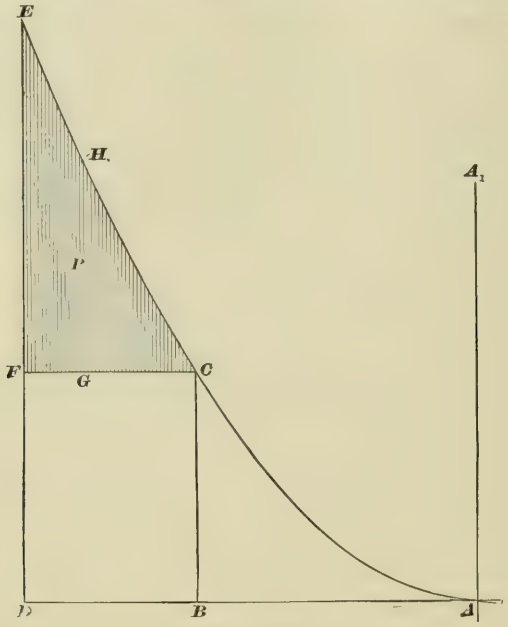

FIG. 403.

centrifugal drum was completely filled with the material from which the water was to be driven out, but this is naturally never the case.

One can picture best, in the following manner, this relation and the distribution of the pressures in the interior of the mass.

The equation $p = \frac{\gamma}{2g}\omega^2 r^2$, which one has arrived at by making $r_0 = 0$, that is, for a drum completely filled, gives a parabola when one views the pressures p therein as ordinates parallel with the axis, and when the radius r denotes the corresponding abscissæ belonging to them. The factor $\frac{\gamma}{2g}\omega^2 = \frac{\gamma}{g}\frac{\pi^2 n^2}{1800}$ is a con-

stant figure for a determined drum speed. In Fig. 403, in which A_1A_1 is the axis of the drum, this parabola is shown, and it is seen therefrom that for any radius, for instance AB, the ordinate BC represents the pressure which will appear at this point if the drum were to be entirely filled with material from which the fluid is to be extracted.

Therefore it appears, for a partially filled drum, in which the mass has about the thickness DB, the pressure on the outer circumference will be denoted by the length $EF = ED - CB$, and the shaded figure EFC gives a graphical conception of the conditions, since for each intermediate point, for instance at G, the vertical ordinate GH represents the amount of the pressure at that point p, for the unit of surface.

Let us assume, for instance, that the diameter of the drum is equal to 3 feet (0.914 m.), and the drum is revolved at a speed of 1,000 revolutions per minute; so that, if the drum was completely filled with material the specific gravity of which is 1.5, we would obtain a pressure on the outer circumference per square foot (0.0929 sq. m.),

$$\frac{1.5 \cdot 62.4}{2 \cdot 32.18} \frac{1{,}000^2 \cdot 4 \cdot 9.87}{3{,}600} \cdot 1.5^2 = 35{,}885 \text{ lbs.};$$

which would be equal to

$$\frac{35{,}885}{144 \cdot 14.66} = 17.1 \text{ atmospheres.}$$

When, as opposed to this, the drum is only filled with material of a thickness of 3 inches = 0.25 foot, one obtains a pressure on the outer circumference of

$$\frac{1.5 \cdot 62.4}{2 \cdot 32.18} \frac{1{,}000^2 \cdot 4 \cdot 9.87}{3{,}600} (1.5^2 - 1.25^2) = 10{,}965 \text{ lbs.}$$

$$= 5.2 \text{ atmospheres.}$$

In this manner the pressure can be determined which is brought out by this process; but for the determination of the tension in the circumference of the drum, there must also be taken into consideration the weight of the drum casing itself, which, through the centrifugal force generated in its own mass, has developed certain strains which are also developed, even when the drum is running empty.

When centrifugal machines are to be used to expel the fluid from wet material, it then becomes necessary to develop as great a pressure as possible in the material, so that the fluid may be completely withdrawn. It is, however, different when it becomes a question of separating cream from milk; that is, when it is desired to separate the more fatty cream from the watery skimmed milk, as is necessary in the case in butter-making. Before the centrifugal process of separation was discovered, this result was accomplished by allowing the milk to stand quietly in open pans, whereby the lighter cream particles rose to the surface, from which they were then skimmed.

The principal trouble with this process was, that the separation was very slow, because the difference in the specific gravity of the two fluids was so very small. The satisfactory working of this method depended largely upon the temperature, and the right temperature was difficult to obtain, and frequently the milk was spoilt and became sour.

FIG. 404.

The centrifugal process does away entirely with these troubles, because the separation is accomplished in an exceedingly short space of time; and in order to determine this, we will first investigate the old process of separation by allowing the milk to stand in a pan.

In Fig. 404, the pan AB is filled with new milk to a height CD, in which watery fluid, with a specific gravity of γ, are numerous small, fatty globules having a somewhat less specific gravity of γ_1; such a globule is F_1, with a volume of V, and a horizontal section F; so is its weight $G = V\gamma_1$ given. As the particle is surrounded by the heavy fluid whose specific gravity is γ, there is therefore underlying it a vertical upward pressure amounting to $P = V\gamma$; whence there is at work on this particle upward a force equal to $P - G = K$.

This force $K = P - G = V(\gamma - \gamma_1)$ is working to force the particle upward, against which is opposed the fluid on the face of the particle. We will designate this opposing force as $W = kFv^2$, wherein v is the velocity of the upward movement,

and k a constant factor. Under the influence of the upward driving force, the particle acquires a velocity expressed by the following formula:

$$V(\gamma - \gamma_1) = kFv^2 \quad \text{or} \quad v = \sqrt{\frac{V}{F}\frac{\gamma - \gamma_1}{k}}.$$

The very slow upward movement is understood when the small difference is remembered in the specific gravities γ and γ_1.

It is well to here remark that the velocity v is entirely independent of the pressure encountered in the fluid column F_1F above it, and therefore it is a matter of indifference to the speed, whether the pan AB is a deep or shallow one; but as the distance that the particle has to travel in order to reach the surface increases with the height, so is it easily understood why shallow pans are used preferably for setting milk.

To comprehend the working in this direction of centrifugal machines, let A, in Fig. 405, be the axis of the drum, in which the milk, during the rotation, takes the annular space between TT and MM. Imagine now at any desired distance $AE = x$, a fatty particle; and to better illustrate, let this particle occupy the space of a small cube whose sides BC and CD are designated by dx.

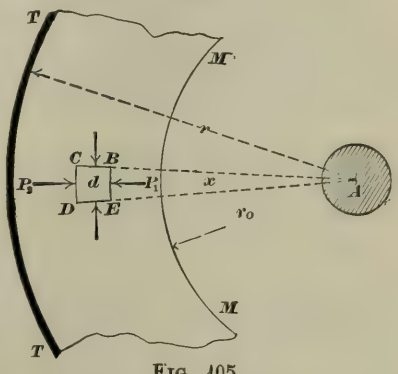

FIG. 405.

Now let this particle be surrounded with a watery fluid having a specific gravity of γ, whereas the particle has a specific weight of γ_1.

On this particle are now working, as in Fig. 404 in the setting pan, the weight $dx^3\gamma_1 = G$, and the upward force of the surrounding fluid is $dx^3\gamma = P$.

In addition to this, the particle encounters the pressure of the surrounding fluid on the faces of the cube. It is clear that of these pressures the two on the faces BC and ED are equal and opposing forces, and therefore do not have to be taken into consideration, as they equalize one another. The two forces, however, which are working on the upper face $BCDE$

and on the under face as well of the cube, combine in the upward movement working on the particle $P = dx^3\gamma$, which works against the dead weight of the particle $G = dx^3\gamma_1$, so that only the excess $P - G = \delta x^3(\gamma - \gamma_1)$ remains, which is of little consequence in proportion to the developed centrifugal force.

There remains now only to observe and determine the forces working on the surfaces BE and CD of the cube from the surrounding fluid, and the centrifugal force developed in the body of the particle. We will designate by p the centrifugal force for a unit of area exerted at a distance $AE = x$ from the axis in the fluid, so that there is working on the inner surface BE a force acting outward amounting to $P_1 = pdx^2$. In the same manner, one has for the surface CD at a distance $x + dx$ from the axis, a working force from the surrounding fluid

$$P_2 = (p + dp)dx^2$$

when $p + dp$ illustrates the pressure acting in this distance for each unit of area. This force works radially inward, opposing P_1. Lastly is determined the centrifugal force working on the particle $C = \frac{\gamma_1 dx^3}{g}\omega^2 x$, which is also, as in the case of P_1, directed outwardly. The combination of these three forces gives a resultant amounting to

$$K_1 = P_2 - P_1 - C = dp \,.\, dx^2 - \frac{\gamma_1}{g}\omega^2 x dx^3 = \frac{\gamma - \gamma_1}{g}\omega^2 x \,.\, dx^3,$$

which is endeavoring to force the particle inward. As this operation is the same for each particle in the fluid, there must therefore be a stratification of these particles on the inner circumference of the mass, whereas the watery parts are forced outwardly as in the same way that the cream is found on the upper surface, in the old process in setting milk for cream in pans.

One easily comprehends, through the deduced formula, why the separation by means of centrifugal methods is quicker than by the setting process in pans. Then, whereas the upward driving force by pan-setting endeavors to produce a movement of the fatty particles expressed by $K = V(\gamma - \gamma_1) = (\gamma - \gamma_1)dx^3$, there is obtained by centrifugal processes the force

$$K_1 = \frac{\gamma - \gamma_1}{g}\omega^2 x \,.\, dx^3.$$

Therefore follows the proportion $K : K_1 :: 1 : \frac{\omega^2 x}{g} = g : \omega^2 x$, wherein $g = 32.18$ feet, indicates the acceleration due to the weight. We have already developed, by an angular velocity $\omega = \sqrt{\frac{g}{x}}$, the same accelerating power as is developed in the upward movements by the pan method. For a drum diameter of one foot, or for $x = r = 0.5$, an angular velocity results of $\omega = \sqrt{\frac{32.18}{0.5}} = 8.02$, therefore in the minute a number of revolutions equal to $\frac{60 \cdot 8.02}{2 \cdot 3.14} = 77$. In practice it is usual to take the number of revolutions as 50 times greater ; it therefore follows that the separating power in centrifugal processes is 2,500 times greater than in pan setting.

The speed of separation is here not dependent upon the amount of the pressure p, that is, from the thickness of the layer in the drum $r - r_0$, but depends upon the radius r and the angular velocity ω, in the same manner that the height of the fluid in the setting pan in Fig. 404 is without influence on the upward speed.

Just as it is desirable to have shallow pans for setting, because then the particles have only a short distance to travel to the surface, for a parallel reason in the centrifugal milk processes there have been introduced a number of partitions or ring-shaped subdivisions (Fig. 406) within the drum, so that the fluid may leave on each of these a deposit of small thickness, thereby not only achieving a rapid separation but also minimizing the pressure on the casing of the drum, as each of these rings takes up its share of the centrifugal force. It will be understood that these rings are entirely closed.

A very important thing to be attained in a centrifugal machine is a regular and even operation ; and another is the diminution of the force of impact to which the bearings of such machines are subjected, and which so quickly destroys their utility. The root of these troubles is in the first place to be found in the unequal distribution of the charge around the axis. As for the drum itself and its axis, careful construction and equitable distribution of the weights of its various parts can be obtained. It is necessary that the drum should revolve perfectly true, and that the centre of gravity of all those masses which take part in

the revolution should lie exactly in the geometric axis. When this, however, is not the case, and the centre of gravity lies at a distance from the axis, then the axis of the drum, through the centrifugal power developed, at each revolution is in quick suc-

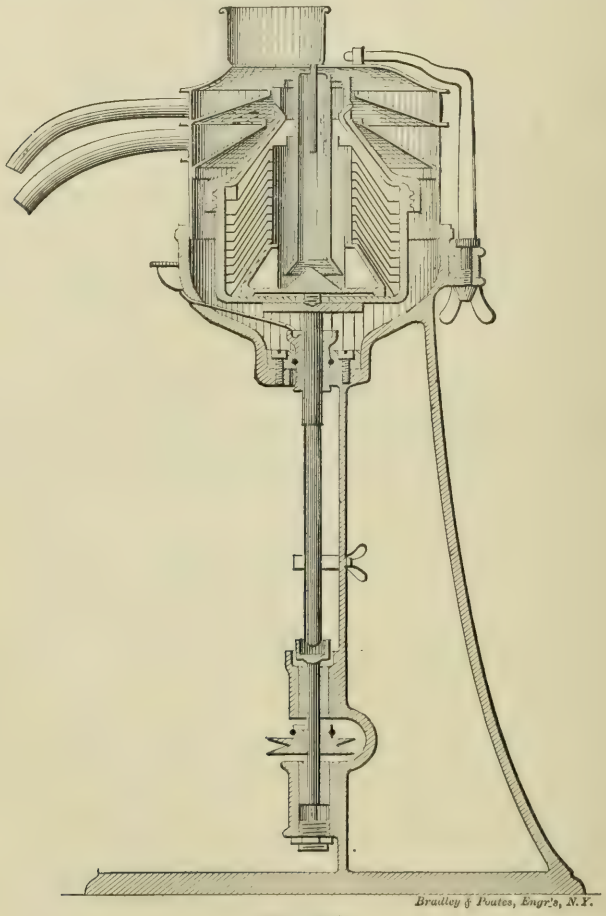

FIG. 406.

cession forced in all directions, from which is developed an uneven and unsteady operation of the machine.

For a quiet running of the drum it is not alone necessary that it shall be cylindrical and that the centre of gravity shall be in the axis, it is also important that the centrifugal force of all parts of the drum shall be equalized. How to obtain this can be seen in Fig. 407. In this AA_1 represents the axis of a

drum T, which is constructed to be perfectly round, whose centre of gravity falls exactly in the axis, and the parts attached are absolutely homogeneous. Imagine now in this drum at B and D, two equal bodies, each of the weight G_1, so attached that they are at an equal distance from the axis and rest diametrically opposite in a plane running through the main axis. In this case, the centre of gravity of the whole drum will not fall outside of the axis.

When the drum is at a standstill, there will be no lateral pressure on the bearings of the axis from the weight. The only thing which occurs in this position is the pressure of the pivot equal to the weight of the whole drum.

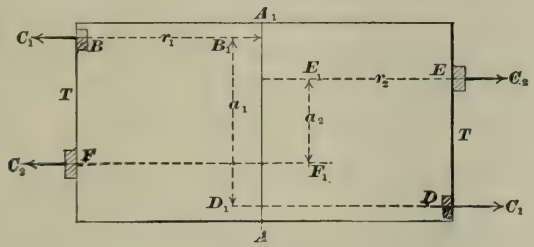

FIG. 407.

If the drum is now made to revolve, there are evoked in all its parts certain centrifugal forces; they arise equally on opposite sides of a homogeneous drum; but this is not the case for the centrifugal forces of the two bodies which have been added, G_1 G_1 as these do not fall in the same direction, but are separated from one another by a certain distance, $BD = a$. In each of these bodies there is produced a centrifugal force of the value $C_1 = \frac{G_1}{g}\omega^2 r_1$, and these two equal but opposing forces make up a Couple the moment of which is found in

$$M_1 = C_1 a_1 = \frac{G_1}{g}\omega^2 r_1 a_1.$$

By the operation of this Couple there will be set up a revolving of the whole axis to the left; that is, contrary to the movement of a watch-hand; and there will be produced side pressures in the bearings of the axis AA_1; and as these pressures are evoked from every direction, the uneasy movements of the machine follow, which are so disturbing.

In order to avoid this trouble it is only feasible to add in addition to the two bodies G_1 G_1 in the same plane, two other equal bodies G_2 G_2 which are placed at E and F, diametrically opposite, but at equal distances, r_2, from the axis; and which are at a distance from one another $E_1F_1 = a_2$, so that the moment of the centrifugal forces of these bodies exactly equals that of the weights G. Therefore follows the formula:

$$\frac{G_1}{g}\,\omega^2 r_1 a_1 = \frac{G_2}{g}\,\omega^2 r_2 a_2 \quad \text{or} \quad G_1 r_1 a_1 = G_2 r_2 a_2.$$

These principles coincide with those which in mechanics are taught as the theory of independent axes. It is well known that in any body three such axes exist, all of which pass through the centre of gravity of this body and are perpendicular to one another. We will designate them as the X, Y, Z axes of a right-angle coördinate system, so that for each of these axes the equations prevail, for instance, for the Z axis,

1) $\Sigma mx = 0$; 2) $\Sigma my = 0$;
3) $\Sigma mxz = 0$; 4) $\Sigma myz = 0$;

in which Σ signifies that the sum of all parts of the body m shall be accounted for. The two equations 1) and 2) indicate only that the centre of gravity must lie in the Z axis in question, whereas the 3) and 4) equations express in general what has been previously said in regard to the two masses G_1 G_1 and G_2 G_2 in Fig. 407. The peculiarities about these independent axes are, that by a single revolution of the body around such an axis the centrifugal forces in every part are fully equalized with one another, so that they exercise no pressure or motion on the bearings of the axis. In a rotation around an independent axis the bearing would be dispensed with entirely, were it not necessary to support the dead weight of the body by means of a pivot, and if it were not necessary for the revolution of the body that the driving belt exert a certain amount of traction which is taken up by a Collar. Where such a driving device is not required, as, for instance, with the well-known toy, a child's top, or one such as is used in lecturing on physics for the demonstration of certain aspects of the laws of color, such a Collar is not present and is not necessary, and the only support in this case is in the point of the top where the weight is equalized. An illustration of a revolving body whose axis has no support

is the earth itself, which in the earliest and dimmest recesses of the past was set to revolving, and has never required a further driving power, its body being supported by the attraction of the other heavenly bodies. The axis extending from pole to pole, on which the globe revolves, is in respect to the previous discussion an independent axis, because a revolution around any other axis, which was not an independent one, would necessarily require and would have a side action on the revolving axis, which, on account of there not being any fixed support of the axis, would involve a change of position of the revolving axis.

We know as a matter of fact that the earth's axis is exposed to slight periodical oscillations called Nutation, but these are caused by the influence of the other heavenly bodies on it, and are in no way caused by the manner of distribution of the parts in the body of the earth. If this were the case the oscillating period would occur with the daily time of revolution, which is not the case.

For this discussion of centrifugal machines the example of the child's top already discussed is of great interest, wherefore I would like to be allowed to examine this subject a little more closely.

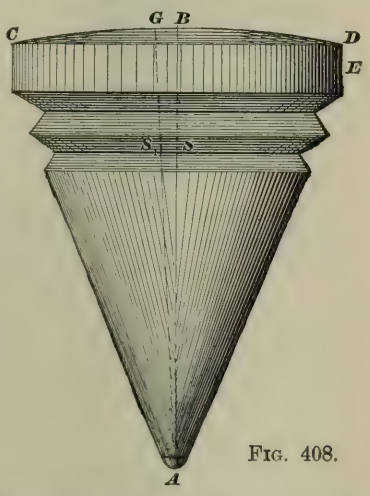

FIG. 408.

In childhood we have often remarked that a top which had been given to us, so long as it did not meet with any accident, revolved around its geometric axis *AB* (Fig. 408) in a very regular manner, so that the painted colored rings on its surface *CD* in revolving gave much pleasure to our childish eyes. We could observe, also, that this axis always held its direction, even when it was in a position at an angle inclined to the vertical. If unfortunately the top had had a piece broken out of it on the edge at *E*, it would then show in revolving an irregular and shaky motion, as in this case the middle line *AB* would be continually swinging back and forth.

The reason for this is easy to understand, as at the point E of the cone a certain piece has been broken off, and the original centre of gravity, formerly at S, is set over on one side at about S_1.

When the top now spins it tries to revolve on an independent axis, that is, one running through S_1, and it follows that at each revolution of the geometric middle line AB of the cone casing around the centre of gravity axis AS_1G calls forth the peculiar irregular oscillations. In order to demonstrate this, I took a metallic top, used in the Physical Department of the Technical High School at Aachen, for experiments (Fig. 409), and fastened on it provisionally, with sealing wax, a small piece of lead, D. The centre of gravity S was herewith transferred to the side, say at S_1. At a first glance one would suppose that this one-sided weighting would cause the top to lean toward the side to which the weight had been attached, and the spinning caused by winding a string around the geometric axis AB would remain unchanged. Observation showed, however, that quite in accordance with the laws of independent axes, the revolving occurred through the centre of gravity S_1 and the axis AS_1 running through it. To prove this I held a

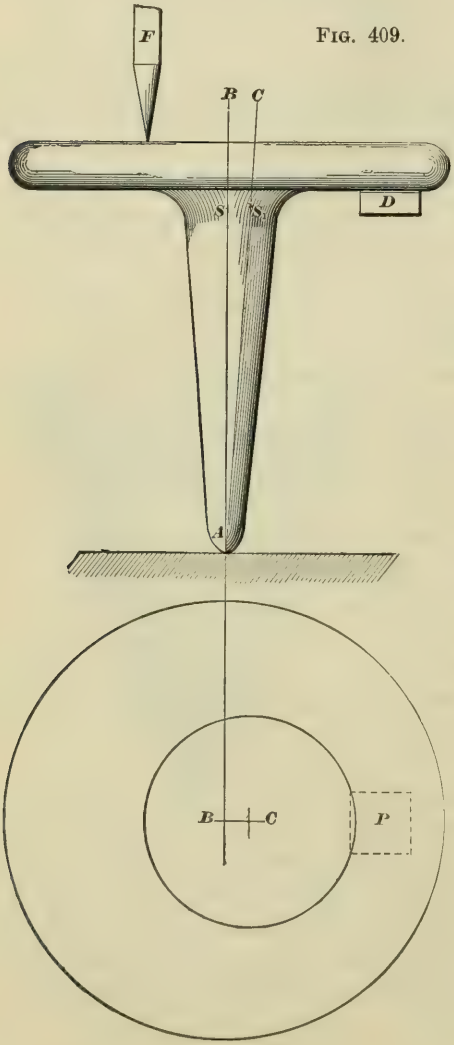

Fig. 409.

soft brush, F, lightly against the paper-covered surface of the top, whereby a circle was drawn whose middle point was in C; therefore from the centre B was moved outwardly toward the side of the centre of gravity S_1. From this it follows that a free moving body given a revolving motion tries so to move that it revolves around an axis, which will coincide with an independent axis.

In applying these fundamental laws to centrifugal machines, it is clear that a drum which is constructed as an exact homogeneous rotary body, revolving empty, develops no lateral motion on the bearing through centrifugal force; therefore the uneven operation does not occur. The only lateral pressure which can occur in this position is from the driving belt, but as this power has always the same direction, only a wearing of the axle bearing, on one side, would occur. A shaky or noisy operation would, however, not be evoked.

This is also true when the drum is partially filled with an easily movable mass, as, for instance, a fluid. This fluid by the rotation of the drum becomes a revolving paraboloid, as in Fig. 401, whose axis is the same as the revolving axis, and it is therefore in this case of a loaded drum that the geometric centre line of the axis is that which one calls in mechanics an independent axis.

Herein lies the reason in centrifugal machines for milk separation, that they, as a rule, operate quietly, and it is therefore usually unnecessary with machines of this class to provide means to correct the great unevenness of operation, which have to be provided for in other kinds of centrifugal machines. These troubles are best explained as follows:

If a centrifugal machine is loaded with a solid charge—for instance, with laundried garments, or with iron sugar moulds in order to clay the sugar loaves—one cannot count upon these bodies being equally distributed around the axis. The centre of gravity in such a loaded drum is generally no longer found in the geometric centre line, as in the case of the empty drum. For these reasons, when the drum revolves there occur the noisy shocks and shaky operation of the same which are so disagreeably apparent when they are running.

To overcome these troubles, it has been tried to permit a lateral movement of the spindle of the axis, by providing it with elastic springs of rubber or steel, which will yield to a certain

extent under the power of side pressure. This arrangement, which is much used, has been adopted in practice, though not the result of any theoretical investigations, and has shown itself to be very useful in partially reducing these troubles. The complete disappearance of them, however, is not possible, as I will now proceed to demonstrate.

To investigate the operation of elastic bolsters on an axis, we will suppose that the axis A (Fig. 410) is surrounded by a collar

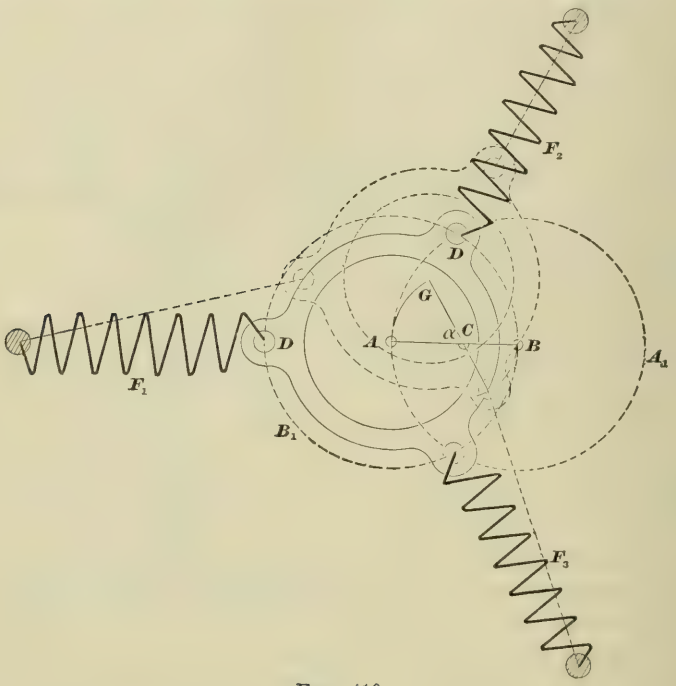

FIG. 410.

DD, supported by means somewhat like F_1, and that it can lean in any lateral direction as soon as a sufficient force is exerted on the bearing in this direction. This mobility, it is well understood, cannot be an absolute or complete one; that is, not one which would allow a side movement even with the smallest given power: on the contrary, the movement will always depend on a certain force, which is determined by the amount of tension of the springs. This power becomes so much greater the farther the bearing is removed from its centre line, as is illustrated by the structure and working of all springs.

We will assume that the centre of gravity of a load in a drum has been shifted from the centre A to one side, say at B; hence, as the bearing would be a fixed one, and one that does not yield, the rotation would proceed around A, and the centre of gravity B would revolve around the circle BB_1. If, however, the bearing yields to a force exerted even slightly, then the rotation would be around an axis passing through the centre of gravity B, exactly in the same manner as in the case of a freely running top; and it would be necessary here, as in the example of the top, that the geometric centre A should revolve around the axis through the centre of gravity B in the circle AA_1. As a matter of fact, neither one nor the other is the case, as the bearing of the axis is neither fully rigid nor movably supported. It is in a position between the two, and it follows therefore that the drum revolves around an axis which lies between A and B. To determine positively the position of this revolving axis is not feasible with our former knowledge; only this can be positively asserted, that the real revolving axis must approach the geometric centre A the less the bearing gives, and the exact opposite is the case; or, the nearer the revolving axis approaches the centre of gravity B, the more elastically is the bearing supported; that is to say, the more easily it is moved laterally.

Assuming, for example, that this axis around which the basket really revolves lies at C, then we have the following: With any rotation, say around the angle $ACG = \alpha$, the centre moves from A to G, and the centre of gravity from B to T. On account of the movement of the centre of the axis and the bearing surrounding it, the spring F_2 would be compressed, and the springs F_1 and F_3 stretched till the force evoked on the bearing by the springs is equalized with that which results from the irregular distribution of the load.

It follows, therefore, that at each revolution of the basket, each spring is alternately compressed and stretched. These springs cannot completely remove the aforesaid inconveniences but only diminish them, so much the more as they are more yielding, and therefore it is the best practice not to make the springs too short.

If it is desired to get rid entirely of these noisy disturbances, occasioned by the unequal distribution of the load, this can only be done by equalizing the load in the drum itself, and many experiments looking toward this desired end have been

made. To accomplish this there must be attached to the axis of the drum certain movable or sliding weights, which continually strive, in the case of side movements of the centre of gravity of the drum, so to move themselves as to readjust the centre of gravity in the centre line. It has been essayed to accomplish this by attaching underneath the axis of the drum a cylinder of small height, partially filled with a heavy fluid (quicksilver or chloride of zinc). And it was thought that this would work as follows:

If A, in Fig. 411, illustrates the axis of the drum, and its centre of gravity lies to one side, say at B, then will the rotation be, according to the preceding discussion, not around the geo-

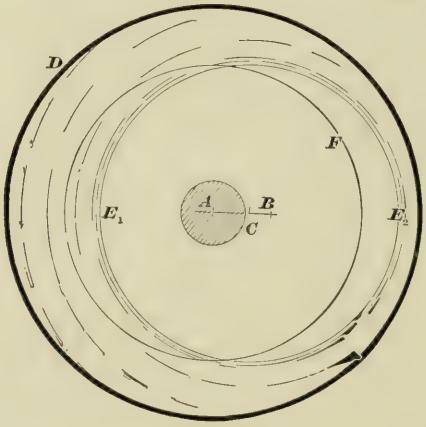

Fig. 411.

metric centre line A, and also not around an axis passing through the centre of gravity B, but around one lying between these two axes, which in Fig. 411 shall be indicated by C. This is naturally only the case when a sufficiently movable elastic bearing of the axis is assured; without this the rotation would be around the geometric centre line A. Now as the fluid contained in the vessel D, which by means of this rotation assumes the shape of a revolving paraboloid whose axis coincides with the revolving axis, the fluid would follow the circle E_1E_2 around the centre C. Therefore, on the side at E_1, opposite the centre of gravity C, the fluid accumulates in greater quantity than on the side of the centre of gravity at E_2, and hence the centre of gravity of the whole approaches the centre A, or under certain conditions coincides with it.

If this should be the case, the irregular shape of the load has ceased to exist and has become regular, and it follows that the drum revolves around its centre line and thereby the troubles have ceased. It is well to remark here that such an operation of the drum is not to be counted upon, and for the following reasons: The fluid in such a cylindrical vessel, by a revolution of the drum, would only be held concentric to the revolving axis C so long as the rotation operated around this axis. When, however, in the manner already discussed, the centre of gravity is moved to A, and in consequence also the rotation occurs around the axis A, the fluid would no longer have the shape E_1E_2, but would have to form itself as a concentric paraboloid to the centre A.

By such an arrangement of the fluid the centre of gravity would lie to one side of the axis, in the point B at first determined, and it appears that the preceding process, with the help of a fluid, is not to be counted upon. A comparison could be made if it were sought to secure the stability of a ship by the use of water instead of fixed ballast. We should be as far from obtaining the desired equilibrium as in this case.

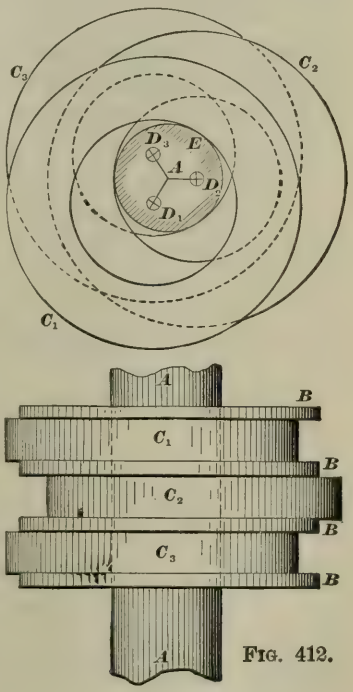

FIG. 412.

As against this a method for reaching the desired result has been much used by Messrs. A. Fesca & Co., of Berlin, which is illustrated in Fig. 412. In this case underneath the drum and fastened to its axis A are four flat plates B, which take part in the rotation of the axis. In the spaces between these plates are three easily sliding rings C, but of sufficient weight when they move sideways to the axis to accomplish the desired displacement of the centre of gravity. These rings during the rotation of the axis, in which they participate through the friction of their under-bearings at B, endeavor

to move outwardly as far as possible from the axis, so that on their inner side they lie against it. When these rings are at an angle of 120 degrees against each other, their common centre of gravity lies in the centre A of the axis, and in this position they equalize one another. When, however, the rings are all simultaneously in the same position over one another, as, for instance, at C_1, then their centre of gravity coincides in the centre D_1. Assume, for instance, that the centre of gravity of the drum and its axis without these rings lies in E, at a distance $AE = a$ from the centre A, and that G_1 is the weight of the drum, and that G_2 represents the weight of all three rings. Then, if the centre of gravity of the whole is to fall in A, the following equation must be fulfilled :

$$G_1 a = G_2 b,$$

in which $b = AD$ represents the distance of the ring centres from the centre A of the axis. It is now necessary to prove that these rings actually move by themselves into the desired position, which is accomplished as follows :

In Fig. 413 A represents the axis, and a loose ring B is shoved

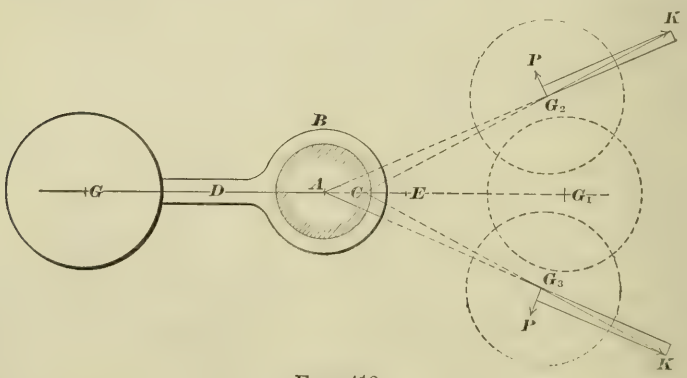

Fig. 413.

over this axis, and that this ring is connected with a weight G by a rod D. This weight G shall, in the same manner as the rings C, in Fig. 412, lie on a disk, so that it necessarily participates in the rotation of the axis by reason of the friction. It follows from this, that this weight, with a tendency similar to centrifugal force, is forced outwardly and draws the ring B against the axis A. If the revolving axis passes through the centre A, the weight remains in any position which it has as-

sumed as a balance, as the centrifugal force passing through the centre A is taken up in every position of the axis. Assuming, on account of the one-sided position of the centre of gravity of the drum in E, the rotation, as a matter of fact, occurs on a revolving axis that is laid outside of the centre A of the rotation axis, for example around C, then the weight G can only be in equilibrium in two positions, G and G_1, in which positions the centrifugal force is directed toward C, also passes through the centre A. In each position of the weight between these, for instance in G_2 or G_3, the centrifugal force K works with a component P so on the weight that it moves to the side opposed to the centre of gravity E, and does not come to a standstill until it has reached the position of G. It appears also that the position in G_1 is that of unstable equilibrium, and at the slightest change of the weight from this position, as, for instance, to G_2, there must be a movement toward G by the component P of the centrifugal force. From this it appears that the weight G always places itself diametrically opposite to the displaced centre of gravity E of the drum, and by this, under certain conditions, the centre of gravity of the drum must be moved to the centre A. And also as in the last case, when the rotation really follows around the centre line A it retains this position; then there is no reason why the weight which has taken the position G should move, and if for any reason this should occur there would result, by the operation already described, an immediate return of the weight to the position opposite G.

Fig. 412 shows an arrangement which is called an "Equilibrium Regulator," where, instead of a single weight, three weights—namely, the three described rings—are used; and the reason for this is easily understood. With one weight G, the equalizing moment would always have the value Gb, b being the distance of the centre of gravity of this weight from the middle of the drum. By using three weights, each having the weight G and the distance from the centre b, the adjustable moment can have any value from 0 to $3Gb$, depending on the position of the weights relatively to each other. It is therefore always possible to

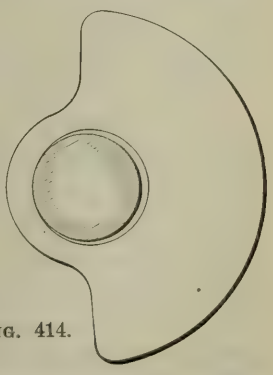

Fig. 414.

equalize them, so long as the moment of the laterally weighted drum lies between these two limit values.

That the single weights are not in the same, but in different planes, in this case over one another, has the advantage that up to a certain degree an adjustment of the load can be accomplished, depending on the height, and in this respect the remarks made in the discussion of Fig. 407 are appropriate.

Finally, to attain the greatest possible adjustable moment, a form of single weight as shown in Fig. 414 is better than the ring-shaped one shown in Fig. 412.

DISCUSSION.

Mr. Frank H. Ball.—This interesting and instructive paper sets forth a theory in the first paragraph of its twenty-first page, which, under certain conditions at least, is not true; and that part of the theory which the author says "can be positively asserted" is the particular part which I believe to be *positively* false.

Referring to Fig. 415, which is supposed to represent a disk, let A be the geometric centre, and B the centre of gravity. If this disk is made to rotate in a plane at right angles to its geometric axis, and no restraint is imposed as to its axis, it will be found that the axis of rotation is at the centre of gravity B and not at the geometric centre A.

FIG. 415.

The mistake which I think Professor Herrmann makes is in assuming that because the normal axis is at the centre of gravity B, therefore, if compelled to rotate about an axis at A, then any flexibility or yielding of this forced axis will make the real axis at a point between A and B.

While this might be true, if the points A and B were almost identical, and the flexibility of axis was sufficient to permit the axis to be easily established at or near B, it could not be the case under any other conditions.

There is a very prevalent misunderstanding of the laws which apply to this particular feature of rotating bodies.

The late J. C. Hoadley, a pioneer of our society and one of its shining lights, wrote an article in regard to counterbalancing steam engines, which appeared in one of the technical journals about ten years ago, in which he made the statement that a reciprocating part could not be counterbalanced by a rotating part; that any counter-weight in excess of that necessary to counterbalance the rotating crank, etc., would only aggravate the difficulty sought to be overcome, because the rotating mass would seek to rotate around its centre of gravity, thus causing a thrust in the pillow blocks in the opposite direction from the excess of weight.

In Fig. 416, let A represent the crank disk arranged for counterweight at B. Let C represent the connecting rod, and D the

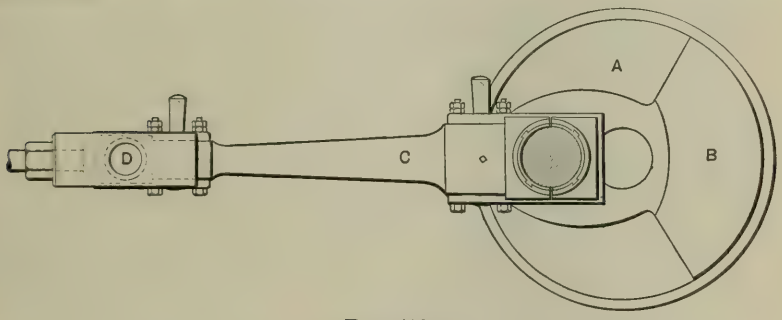

FIG. 416.

cross head which with piston attached constitutes the reciprocating part of an engine.

Mr. Hoadley's idea was, that weight placed at B would not counteract the unbalanced thrust of the reciprocating parts, but would aggravate the difficulty, because the excess of weight at B would seek to approach the geometric centre and thus establish a new axis nearer the centre of gravity. This theory was supported by quotations from a publication issued by the Defiance Machine Co., Defiance, O., illustrating their balancing machine, in which publication the statement appeared in substance as follows: "If a rotating mass is made to rotate around an axis not coincident with its centre of gravity, the effect will be to deflect the axis away from the heavy side, and the light side will be found to be permanent." Applying this theory to Fig. 417, suppose the disk here shown has its centre of gravity at B, and its axis of rotation at A, then this theory asserts that the effect of rotation would be to deflect the shaft supporting the disk in the

opposite direction from B, thus bringing the real axis of rotation between A and B and making the light side permanent.

It so happened that at the time of Mr. Hoadley's article I was engaged in a series of experiments to determine the best relation of counterbalance weight to the weight of reciprocating parts, and the data thus obtained being diametrically opposed to the theory just mentioned, the facts as they appeared from these experiments were used in a reply to Mr. Hoadley, which also appeared in one of the engineering publications. Those who remember the incidents referred to will also recall that when Mr. Hoadley was heard from again he had investigated for himself and found that he had been all wrong, and it will also be remembered that he gave the public a very interesting description of his experiments, in which he used a disk mounted on a somewhat flexible mandrel similar to that shown in Fig. 417.

After rotating this disk on the centres of a lathe and finding that it ran true, he attached a weight to the disk on one side, as, for instance, at B.

The effect of this excess of weight at B, he found to be that the axis sprung toward B, and the point C was the prominent side, which is just the reverse of what he had formerly stated, and the real axis was the other side of A, and not between A and B as Prof. Herrmann says it will be.

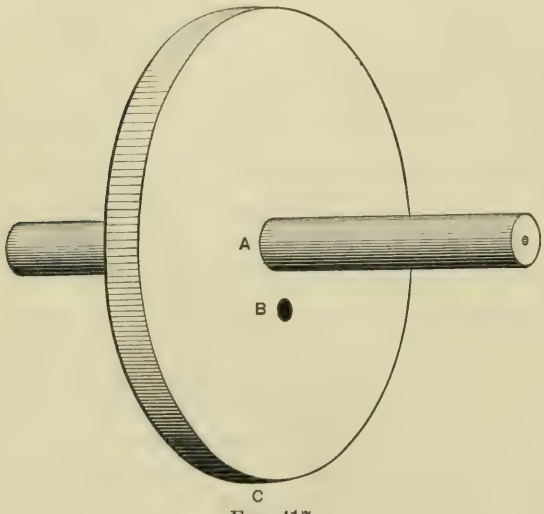

Fig. 417.

Just what takes place in the various evolutions of rotating and revolving bodies is a very complex problem and difficult to follow.

This particular problem under consideration will be simplified by keeping in mind that, when in Fig. 417 the disk is made to rotate, it primarily rotates about its centre of gravity B. If another axis is

established as at A, then the former rotation about its centre of gravity B does not cease, but a new motion is introduced, and the mass considered as concentrated at its centre of gravity may be said to revolve about the point A, and at each such revolution the mass also rotates about its centre of gravity B. To get a clearer idea of both these motions, let the axis A be supposed to be outside the boundaries of the disk and attached to it by a forked connection engaging trunnions located at B. With this arrangement the disk in revolving around this axis just described might or might not rotate about its own centre of gravity B, and its rate of rotation might coincide with the rate of revolution, or it might be faster or slower.

If the axis of revolution is within the boundaries of the disk, then the rate of revolution coincides with its rate of rotation.

Having these two motions in mind, it is not difficult to see:

First, that if in Fig. 417 the point A is established as an axis, then the disk primarily rotates about its centre of gravity B, and this centre of gravity is compelled to revolve around the axis A, following a circular path whose radius is the distance from A to B, and the resulting centrifugal force is exerted to bend the axis towards C, which satisfactorily accounts for the phenomenon described in Mr. Hoadley's experiments already referred to.

Second, if the forced axis A be suddenly released with the disk in motion, then instantly the centre of gravity B ceases to revolve around A, and begins to move in a tangent to its former path of revolution; and if this radius of revolution had been small, as would be the case in Fig. 416, then the resulting tangential motion would be slight and might quickly cease, while the rotation about the centre of gravity B might continue, in which case the light side would be prominent, which accords with the law of rotating bodies, which asserts that the axis of a rotating mass if free from restraint will pass through its centre of gravity.

It seems to be true that under certain conditions an entire release of the axis A is not necessary in order that the axis be established at B, and particularly so if the distance from A to B is relatively small, and it does not seem to be known just what the limitations are in this respect.

With our present knowledge, it is not safe to assume that the axis will be at B if any restraint is exerted at A, and if the axis is not at or near B it will not be near the point A on the side toward B, but on the opposite side of A, and both A and

B will be on the same side of the real axis. If any one doubts this, let him try the very simple experiment described by Mr. Hoadley.

Mr. W. W. Dingee.—Centrifugal machines are used for extracting oil from bolt cuttings immediately after rotation commences. The cuttings arrange themselves so as to secure equilibrium.

The same thing occurred in the centrifugal pipe moulding machine used about 1850 in Baltimore. This automatic tendency to balance where matter is free to move inside of a rapidly revolving cylinder might be made to elucidate what is obscure in the process of balancing.

*Prof. Gust. Herrmann.**—Although I am much obliged to Mr. Frank H. Ball for the kind attention which he has spent on my paper, yet I cannot agree with his objections, for the following reason.

Mr. Ball argues: "That if in Fig. 417 the point A is established as an axis, then the disk primarily rotates about its centre of gravity B, and this centre of gravity is compelled to revolve around the axis A, following a circular path whose radius is the distance from A to B," etc. After this supposition each point of the disk must be subjected to two different motions: first, a rotation about B, and second, a certain revolving motion in a circular path of the explained character. Such a condition would require that the different parts of the mass in the drum were sufficiently movable, as is the case with a liquid or a paste or similar mass. But under this condition there is no need at all of any means for balancing, as the mass arranges itself so as to secure equilibrium as Mr. Dingee states, and as I noticed in my paper on its nineteenth page. Here is only to be supposed a drum, loaded with a solid charge, like iron sugar-moulds, the parts of which are not able to have a relative motion one against another. Such a drum must be considered as a solid body, and if it is turned about a fixed axis, any point of it can only accept a single rotation about this fixed axis; no other motion such as those above suggested will be possible. Therefore, that supposition of two different motions cannot be true, and I cannot imagine that right conclusions could be drawn out of a wrong supposition.

I agree with Mr. Ball that the whole progress is a very complex

*Author's Closure, under the Rules.

problem, and difficult to follow, and I am glad to say that now I am able to add something more about the matter in question, after having turned it in my mind in consequence of the discussion. I can give a full proof that the real axis must be situated between A and B, and I think I can explain, too, in some degree, how to calculate the place where this axis must be. May I be permitted to explain this in a short manner?

Imagine, for simplicity of deduction, the whole mass of a loaded drum concentrated in two points, C and D, Fig. 418, diametrically on both sides of the fixed axis A, and at equal distance from the latter, $r = AC = AD$. The masses concentrated in these points may be M in C and m in D. If $M = m$, then the centre of gravity lies in the axis A, and in rotating the drum no thrust will be caused by the axis A against its bearings. Rotation might be effected then without bearings at all, as in the case of the aforesaid child's top.

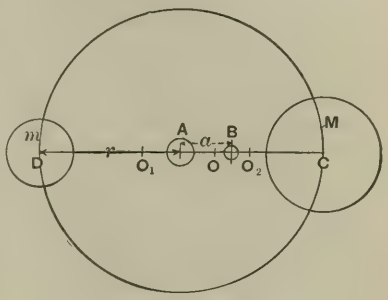

FIG. 418.

Now we will suppose M larger than m. The centre of gravity is then found in B by the equation

$$M(r - a) = m(r + a); \text{ or, } (M - m)\, r = (M + m)\, a,$$

if a be the distance AB.

At first we suppose the bearings of the axis A perfectly rigid and without elasticity. If we rotate the drum with the angular velocity ω, we shall find the thrust P of the axis against its bearing:

$$P = M\omega^2 r - m\omega^2 r = (M - m)\, \omega^2 r = (M + m)\, \omega_2 a.$$

This force is working in the direction from A to C, and the bearing acts against the axis A with an equal force in the opposite direction from C to A.

Now we conceive the bearing perfectly movable or entirely taken away. The drum will continue in rotation, but no longer about the axis A. That could not be, because there is no bearing to take up the resulting thrust. Therefore, if it further rotates, as

it does without doubt, it can only rotate about an axis which is not subjected to any thrust. This axis passes through the centre of gravity B, because we have for this point:

$$M\omega^2(r - a) = m\omega^2(r + a).$$

Therefore are the two centrifugal forces of the masses M and m in equilibrium as soon as the drum will rotate about an axis in the centre of gravity, and so it does in full accordance with the experiment with the top. (Fig. 409.)

Now let us suppose the real condition of an elastic bearing; that is, of a bearing which will yield and move laterally, if there is a force working against it, so that this lateral motion will be the larger, the greater the thrust of the axis is. When we now rotate the drum, the latter cannot revolve about the axis A, because there would be a thrust which must move the axis sidewise; it also cannot rotate about an axis in B. Hence in this case there would be no thrust that could maintain the axis in this lateral situation. We conclude from this that the drum will rotate about any other axis. Where this real axis of rotation is situated, is not known yet. I have said, it lies no doubt between A and B. Mr. Ball has another opinion. Let us see what mathematics say.

For the drum in question must be equilibrium between the two centrifugal forces of M and m, together with the force with which the bearing will react against the thrust of the axis A. Now, the real axis of revolution may be situated in a threefold manner, either between B and C, or between A and D, or between A and B, if we exclude the impossibilities of a real axis out of the disk beyond C or D. It is easy to show that the two first situations of a real axis between B and C or between A and D are not possible.

Let us, for instance, suppose that the real axis were situated between A and D, as Mr. Ball seems to assume, and may be O_1, an axis at the distance $z = AO_1$ from the geometrical axis A. The drum, if rotating about O_1, will cause a thrust of the axis against its bearing,

$$M\omega^2(r + z) - m\omega^2(r - z) = (M + m)\,\omega^2(a + z).$$

This force would have the direction of the larger centrifugal force, that is, from the centre A towards C, and the bearing would

have to work in the opposite direction from A to D. That is quite impossible, as it would not be in accord with the supposition that the axis were leaning towards the side of D.

In the same manner we can show that the real axis cannot be in O_2, between B and C. Then, if such would be the fact, we must accept that the bearing would work against the axis with a force

$$m\omega^2(r+z) - M\omega^2(r-z) = (M+m)\,\omega^2(z-a)$$

in the direction from the centre A against C, and that would not be in accord with the leaning of the axis towards the side of C.

Therefore, the real axis of revolution can only be situated between A and B, as I assumed in my paper. But we can also calculate the place O between A and B, in which this axis will be, by the same simple formula.

Let z be the distance of this axis O from the centre A ; then we have for the equilibrium the condition:

$$M\omega^2(r-z) - m\omega^2(r+z) - p = 0\text{; or, } p = (M+m)\,\omega^2(a-z)$$

if p signifies the reaction with which the bearing will act against the axis A in the direction from A towards D. We may therefore estimate the distance z if we know the distance a of the centre of gravity B from the centre, and if we know the law according to which the pressure p exerted by the springs of the bearing will depend from the lateral motion of this bearing.

Any further explanation would go too far, and I have already too much tried the patience of the readers. I only may be allowed to express my hearty thanks to Mr. Frank H. Ball for having given the occasion to get some more light in a matter hitherto dark and complex.

Finally, concerning the mentioned experiment of Mr. Hoadley. This experiment cannot prove anything in the matter here treated, because all relations are different. The flexible mandrel of Mr. Hoadley, supported by the perfectly fixed centres of a lathe, is quite another thing from the stiff axis of a centrifugal drum guided by a bearing in which it can move laterally. While the real axis of revolution in the centrifugal machine is able to swing within a certain cone, the axis of revolution of the said mandrel can never change; it is always fixed by the straight line between the firm centres of the lathe. The influence of the one-sided

weight in the mandrel could be no other than to produce a bending of the mandrel, which could be calculated before without any experiment at all. If we chose to examine, by experiments, the conditions of the centrifugal drum, then the best and perhaps only instrument will be the top; and as often as we may repeat the trial, we shall always find the same result, as is noticed in the paper.

DXLIX.*

THE HISTORY AND MODERN DEVELOPMENT OF THE ART OF INTERCHANGEABLE CONSTRUCTION IN MECHANISM.

BY W. F. DURFEE, WEST NEW BRIGHTON, N. Y.

(Member of the Society.)

I AM to speak to you of the history and modern development of the art of interchangeable construction in mechanism.

This subject is so vast that it is impossible to treat it exhaustively in a single paper; nothing short of a copiously illustrated volume can convey an adequate understanding of the long, devious, and weary way traversed by mankind in the journey toward the highest attainable perfection in handiwork, tools, machinery, and their products.

The most that I hope to succeed in doing on this occasion is to excite an interest in the history of the development of mechanical processes and apparatus, by brief notices of the more important inventions which, like mile-stones, mark the various stages of the road along which improvement has journeyed.

The study of the development of the mechanical adaptation of means to ends is as essential to the thorough education of an engineer as a knowledge of biblical history and the *Lives of the Fathers* to a theologian, or an acquaintance with *Cæsar's Commentaries* and *Jomini's Art of War* to a soldier who aspires to command. Study of the laws of success is always assisted by an investigation of the causes of failure. Mechanical progress in the future can receive no more powerful acceleration than that furnished by a thorough knowledge of the laws underlying the successes and failures of past time.

That great Scotch-Englishman, Thomas Carlyle, tells us that "Man is a tool-making animal, weak in himself, and of small stature; he stands on a basis, at most for the flattest-soled, of

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

some half square foot, insecurely enough; has to straddle out his legs lest the very wind supplant him. Feeblest of bipeds, three quintals are a crushing load for him; the steer of the meadow tosses him aloft like a waste rag. Nevertheless, he can make tools, can devise tools; with these the granite mountain melts into light dust before him; he kneads glowing iron as if it were soft paste; seas are his smooth highway, winds and fire his unvarying steeds; nowhere do we find him without tools; without tools he is nothing; with tools, he is all." Let us examine some of the work of this tool-devising and tool-using animal, and note his exercise of the creative power with which he has been endowed, in the invention of tools and processes that enable the artisans of our day to produce those marvels of interchangeable mechanism which are the crowning glory of human skill in these closing years of the nineteenth century.

In looking backward through the long perspective of the receding centuries for the first indication of an appreciation by man of the advantages of interchangeable construction, we recognize in the hands of the pioneers of the race, as they emerge from that "great deep" which, "without form and void," lies beyond the limits of authentic history, weapons and tools that possess the elements of interchangeability in as high a degree of development, relative to the knowledge of the times, as the most refined illustration of the art in our own day.

The bow of the primeval man had a sinewy string that would fit any other bow; his arrows were adapted to any bow-string, his paddle could be used in any canoe; the head of his spear would fit any shaft, and his uncouth hammer of stone, from the great interchangeable manufactory of nature, would drive a tent peg into the earth, or a skull into fragments.

There is nothing improbable in the supposition that all the primitive arts originated in man's necessities; and that a very general diffusion of a successful practice of those first essential processes was not only the explanation of their preservation, but was the creator of wants more or less artificial, to satisfy which, other arts were devised, which in their turn led the way to more complex needs—one satisfied want creating an unsatisfied desire, which inventive genius gratified.

Thus, step by step, through long ages past, mankind has progressed.

This slow engrafting of the artificial upon the natural man has been noticed by many ancient writers. Virgil says :

> "Jove willed that man, by long experience taught,
> Should various arts invent by gradual thought."

Those who undertake to trace backward the development of civilization cannot fail to note that all the more important inventions and discoveries have had, as a rule, more than one claimant. This rule has so frequently asserted itself, that it seems to justify the belief that when, in the fulness of time, the world had become prepared for a decisive advance in the sciences or the arts, an overruling power indicated simultaneously to minds separated, oftentimes by continents and oceans, some way to satisfy the growing needs of mankind.

Those whose prophetic minds are caused to see clearly not only the scope of a pressing need, but also the means of satisfying it, we call discoverers and inventors; and such are deserving of honor and reward commensurate to the value of their services in the cause of human progress. But, unfortunately, they have too often been defrauded of a just recognition, and some paltry pilferer has been allowed to appropriate a recompense to which he had no righteous claim. A conspicuous instance of honor bestowed upon the undeserving is furnished by the name of the western world. Emerson tells us that Amerigo Vespucci was a "pickle-dealer at Seville, who went out in 1499, a subaltern with Hojeda, and whose highest naval rank was boatswain's mate in an expedition that never sailed, and who managed in this lying world to supplant Columbus and baptize half the earth with his own dishonest name."

Names long established in geography and politics are not readily interchangeable, but were it otherwise, one of the just results of this grand gathering of the nations on the soil of the continent discovered by Columbus would be the substitution of his name in all coming time for that of the "pickle-dealer of Seville."

The term "interchangeable," as applied to mechanism, implies an ability to make a machine and all its component details exactly like a model; and it is obvious, in the making of a multitude of examples of a specific machine, if the several details are made exactly like those of the model, that any one of these details can take its appropriate place and

perform perfectly its allotted functions in any one of the machines.

In decorative art, what is sought is a systematic and pleasing adaptation of ornamental variety to the requirements of a particular object or situation, and uniformity of detail is generally a sacrifice of artistic effect; but in the design of mechanism, true art consists in the fitness of all its parts for their intended structural and functional purposes; and in the duplication of machines conspicuous uniformity never advertises the poverty of art, but rather furnishes, by a satisfying sense of the "eternal fitness of things" mechanical, a material realization of true beauty, which has been defined as "the completeness of the whole, and the perfection of the parts." *

The more prevalent modern idea of the interchangeable in mechanism supposes a super-refinement of accuracy of outline and general proportions that is not always necessary or even desirable. It would be a criminal waste of time and substance to fit a harrow tooth with mathematical accuracy, but yet any harrow tooth should have a practical interchangeable relation to all harrows for which it is designed. The instructive rewards of folly would certainly overtake him who should attempt to make ploughshares and coulters with radical exactness; nevertheless, these essential parts of ploughs should be interchangeable among all ploughs to which they are adapted.

It is fortunate that there is a recognized practical roughness of interchangeability, and that the refinements of agriculture have not in our day reached the point that that great captain of romance, Lemuel Gulliver, tells us had been attained in the wonderful kingdom of Laputa, which he claimed to have discovered. This allusion to the common practice of our time, of making the parts of agricultural implements and mechanism roughly interchangeable, naturally calls to mind the earliest method of making the metallic parts of implements and apparatus in like manner—the art of casting. This art has come down to us from a period of which history is ignorant, and from a people whose foot-prints have been obliterated by the dust and débris of uncountable centuries. We shall never know who made the first crude casting, or the circumstances attending its production. In that rude period, doubtless—

* "True beauty consists in the completeness of the whole, and the perfection of the parts."—*Rev. Theodore Parker.*

"Th' invention all admir'd, and each how he
To be th' inventor miss'd ; so easy it seem'd,
Once found, which yet unfound most would have thought
Impossible !"

Few if any of the arts have had more potent influence upon the progress of humanity on its long journey from primitive barbarism to what each succeeding age, even to our own day, has complacently described as "modern civilization." Whoever the discoverer of this art was, whether the Vulcan of mythology or Tubal Cain of the Scriptures, he is deserving of most honorable recognition; and if present civilization was disposed to be as just to its creators as that of ancient Greece, it would imitate its altars "to the unknown god," by the erection of a monument of no mean proportion to the unknown inventors who by their discoveries laid broad and deep the foundations of the arts of our time.

It is not germane to our purpose to dilate upon what has been accomplished by the art of casting among ancient peoples; examples of castings in brass and bronze, designed both for ornament and utility, abound in the museums of the world. But perhaps it may not be without interest to call your attention to an evidence of the antiquity of castings of iron, that has not hitherto received much attention. It is well known that the heads of the battering-machines used in ancient warfare were sometimes made of iron, and were shaped like the head of a ram; from this fact, and the suggestion of its movement when in action, these machines were called battering-rams. The heads of these machines were exposed to a terribly destructive impact when in use, and therefore it is justifiable to suppose that they would have been made of a material easily shaped and from which duplicate heads could quickly be supplied. Forged iron does not fulfil these conditions, being difficult to obtain in large masses at the time, and it is absurd to suppose that the ancients would have expended the time and labor necessary to carve a lump of wrought-iron in the elaborate, realistic way indicated by all the representations of battering-rams shown on ancient monuments. As it is certain that these rams' heads were often made of iron, it appears to be more than probable that some tough variety of cast-iron was used, in which case a new head could readily take the place of a broken one, and the business of the siege go on without serious interruption.

Another evidence of the appreciation of the value of interchangeability of similar parts, in ancient weapons of the heavier sort, is found in the gearing for twisting the funicular springs of catapults. This gearing is described by Rollin * as being made of cast brass or iron, but the Chevalier Folard † states that it was made of cast-iron.

The origin of the catapult is uncertain, but it is believed to have been used by Nebuchadnezzar at the sieges of Jerusalem and of Tyre (586, 588 B.C.). Thus early did the military engineers perceive the advantages of interchangeability among the more important similar metallic parts of machines of war; and thus early does cast-iron appear as a material from which some of these parts were constructed.

Neglecting minor examples of the interchangeability of parts produced by the art of casting, we come to the making of movable types. This art is without doubt the most important exemplification of the grand results that have sprung from the original discovery that metals could be given any desired form by melting and pouring them into appropriate moulds. The printer's art rests firmly and solidly upon the art of casting; for the experience and skill of man for the past four hundred and fifty years has utterly failed to find a satisfactory substitute for the art of casting by which to produce with requisite economy and precision the interchangeable type, whose invention marks distinctly the beginning of a new era in the life of man upon the earth. As soon as movable types were invented, it became evident that extreme accuracy was essential in their production; in each variety of character in a font, all types of the same letter must be alike both in face and body, and the bodies of all the types must be so related to each other, and to the "quads" and "spaces," that a given length of line can be perfectly filled. In the history of mechanical development nothing possible of attainment by ingenuity and handiwork has ever been asked of the artisans of the world, that they did not immediately supply; so this demand for a precision of execution unheard of before was met by workmen whose skill was quite equal, if not superior, to any of our time.

Some recent careful examinations and measurements of repe-

* *The History of the Arts and Sciences of the Ancients.* By Mr. Rollin. 3 vols. London, 1768.

† *Histoire de Polybe*, Amsterdam, 1729.

titions of the same word in black-letter volumes about four centuries old, prove the correctness of the statement just made, for the agreement is quite as close as noted in modern publications. In estimating the skill of the original type-founders, we must not fail to remember that they were destitute of all those tools which are considered essential by modern skilled workmen for the production of accurate work in metal.

Lathes were crude and sporadic.

The "planing machine" was three hundred years in the future, and the "shaping machine" fifty years more remote.

The "micrometer" was one hundred and eighty years ahead of them.

The "milling machine" was far below their horizon of time.

The "black-lead pencil" had not been invented, and the English unit of measurement was a "barley-corn."

Besides the art of casting, their dependence for the execution of good work (such as that required on the moulds for type) was on hammers, chisels, files, gravers, scrapers, grinding, the bow-drill, and burnishers; these were the tools which skilful hands and keen eyes used in those days in the working of metals.

While the originators and early practitioners of the art of printing were successful in casting (the early printers were also type-founders) types that would interchange among those of the same founder, the types made by different founders would not interchange with each other; and it is to the credit of American artisans that they have perfected a system of manufacture by which it is quite possible to "make up" a "form of type" as large as the side of an ordinary newspaper, and, notwithstanding the fact of the types having come from half a dozen foundries, there will not a type leave its place when the form is held horizontally by its "chase."

In recent years the art of casting type has been combined with the art of "composing" or assembling them into words and sentences. By means of exquisite mechanism actuated by power and controlled by keys properly fingered by the compositor, certain letter matrices are arranged in exact order at the bottom of a mould. Whenever a sufficient number of such matrices are assembled to form a line of predetermined length, melted type-metal is forced into the mould, and as soon as it solidifies, the solid line of type (hence the name, Linotype, of the apparatus) is thrown out of the machine. This machine is

a splendid example of the modern system of interchangeable construction, and for accuracy of workmanship and the perfect adaptation of means to ends, as well as for its rapidity of operation, it deserves to take rank among the wonders of human ingenuity.

The art of stereotyping is only an amplification of the art of casting single type; and to such perfection has the art attained in some of the larger newspaper offices that it is not unusual to make a papier-maché mould from the flat form of type, curve this mould to a proper radius, cast the stereotype from the mould, secure it to the cylinder of the fast press, and have the newsboys crying the *n*th edition of the *Heraldic Tribune and Cosmopolitan Sun* within twenty minutes after the arrival of the "form" in the stereotype room of the printing-office.

For the invention of the art of printing the world is indebted to Germany; and if that great nation,

> "Renowned for arts and arms,
> For manly talent and for female charms,"

had never made any other contribution to the commonwealth of knowledge, it would still be entitled to the grateful homage of mankind throughout the ages yet to be. So noble an art as that of printing deserves the best that thought of brain and skill of hand can give. It has made the possibility and potentiality of knowledge the common heritage of all lands and peoples, and constituted itself the integrator and conservator of the science of the whole world. Nations may rise or fall, dynasties may perish; but so long as man dominates the earth, the art of printing will be the educator of the succeeding generations, and will hand down from father to son, even unto the end of time, the ever accumulating wisdom of the rolling years.

For more than a century after the invention of printing, very little progress was made in mechanical invention. Feebly and with uncertain grasp the intellectual powers of man contended with the physical forces of nature; and all the world seemed to be awaiting the coming of some dominant genius like that of the great Sir Francis Bacon, through whom came such revelations of the force and scope of inductive reasoning as changed the currents of civilized thought, and conferred new powers and possibilities upon the mind of man.

From the time of Lord Bacon, human intelligence seemed to

arouse itself from the torpor of past ages, and to assert, by manifestations of a latent ingenuity, with an ever growing confidence, its creative power and supremacy over material things. This growing belief in the vast possibilities of the future, respecting discoveries in science and inventions in art, was quaintly expressed by Sir Hugh Platt, who, writing in 1595,* says "that it is time, and high time, to let the world and all posterity to understand, that if our English artist (whereof sundrie in my knowledge are of such rare and singular conceipt, as they are, yea, and would also be found willing, if the stipend of honor and merit were now propounded, fully to discover a world of new inventions) . . .

"They would bring forth so many, so rich, and so inestimable buds and blossoms of skill, as neither any civil policy that hath been hitherto shut up in printed books, nor any religious charity that hath been so often and so divinely sounded in at our deaf ears, could yet produce or show any comparable effects unto them." After briefly specifying a dozen inventions, for each of which large claims are made, Sir Hugh says: "I have always found it in mine own experience, an easier matter to devise many and very profitable inventions, than to dispose of one of them to the good of the author himself." In which conclusion, probably, most modern inventors will agree.

Among the first elements of mechanism to be made interchangeable by means of machine tools was the toothed gear wheel. An appreciation of the advantages of accuracy in the form of its teeth, and uniformity in their spacing, was first decisively manifested by makers of clocks and watches.

A general idea of a wheel dividing and cutting machine was suggested by Dr. Hook in the latter part of the seventeenth century, but the first tool of the kind actually used is believed to have been made in France, and to have been similar to one described in Bion's work on mathematical instruments, published in 1702. The French were very much in advance of other nations in the invention of tools and apparatus for the making of clocks and watches. In a work published in Paris in 1741† there are detailed engravings of three gear-cutting engines, two of which

* *A discoverie of certaine English wants which are royally supplied in this treatise.* By H. Platt of Lincoln's Inn, Esquire. Printed at London by P. S. for William Ponsonby, 1595.

† *Traité de l'Horlogerie mécanique et pratique.* Par Thiout. Paris, 1741.

have perforated dial plates, and the third a worm wheel and screw, for regulating the spacing of the teeth in the wheel being cut. The method of originating the divisions in the plates of these French machines is not described, but about the same period, Henry Hindley (the inventor of the "hour-glass worm"), a clock- and watchmaker of York, England, constructed a machine for cutting gears which had a perforated dial plate. In a letter to John Smeaton (dated November 14, 1748) he explains the method of dividing the plate of this machine. This method involved the employment of a mechanical device which, in the language of the workshops, we would now call a "jig" (see Tomlinson's *Cyclopedia*, article "Graduation"); and Hindley is believed to have made the first record of the use of such a tool.*

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*Hindley's method of dividing was an original and highly ingenious method of "stepping." It is described as follows in a letter which he addressed to Smeaton on November 14, 1748, and as he entrusted it as a secret to Smeaton, it was not published until 1786. Hindley says: "First choose the largest number you want, and then choose a long plate of thin brass:—mine was about 1 inch in breadth and 8 feet in length, which I bent like a hoop for a hogshead, and soldered the ends together, and turned it of equal thickness upon a block of smooth-grained wood, upon my great lathe, in the air, (that is, upon the end of the mandrel):—one side of the hoop must be rather wider than the other, that it may fit the better to the block, which will be a short piece of a cone of large diameter:—when the hoop was turned I took it off, cut and opened it straight again. The next step was to have a piece of steel bent into the form as per margin, [Fig. 419] which had two small holes bored in it of equal bigness, one to receive a small pin, and the other a drill of equal size. I ground the holes after they were hardened, to make them round and smooth. The chaps formed by this steel plate were as near together as just to let the long plate through. Being open at one end, the chaps so formed would spring a little, and would press the long plate close by setting in the vice. Then I put the long plate to a right angle to the length of the steel chaps, and bored one hole through the long plate, into which I put the small pin; then bored through the other hole; and by moving the steel chaps a hole forward, and putting in the pin in the last hole, I proceeded till I had divided the whole length of the plate. The next thing was to make this into a circle again. After the plate was cut off at the end of the intended number, I then proceeded to join the ends, which I did thus; I bored two narrow short brass plates as I did the long one, and put one on the inside and the other on the outside of the hoop, whose ends were brought together; and put 2 or 3 turned screw-pins, with flat heads and nuts to them, into each end, which held them togeather till I riveted two little plates, one on each side of the narrow plate, on the outside of the hoop. Then I took out the screws, and turned my block down till the hoop would fit close on; and by that means my right line was made into an equal divided circle of what number I pleased. The engine-plate

FIG. 419.

In the year 1783 an English mechanician by the name of Rehé made a gear-cutting machine having a dial plate nineteen inches in diameter. Some of the cutters used in this machine were made of solid steel, and others had steel teeth inserted in a hub. The teeth of the cutters were shaped to give the proper profile to the teeth of the wheel being cut, and their general form is very suggestive of certain popular cutters used at the present time. As showing the estimation in which good machinery was held in England at the close of the eighteenth century, the fact that this machine was sold, after the death of Mr. Rehé, for the sum of £700 may be of interest. As a companion to his gear-cutting machine Mr. Rehé made a special machine for grinding and shaping its cutters. The work was done by revolving disks and cylinders of copper, fed with emery and oil. This cutter grinder is believed to have been the first of a race whose various representatives in our day are regarded as indispensable aids to the production of accurate interchangeable work.

In the year 1775 Jesse Ramsden completed in London the most ingenious and perfect piece of mechanism that, up to that date, had been produced for accurate reduplication—his dividing engine, by which circles within its capacity could be divided into any desired number of equal parts. This machine immediately occasioned important changes in the construction of nautical instruments, and furnished the means for increasing the accuracy of the perforated dial plates of wheel-cutting machines; in fact, the plate of Rehé's machine, already mentioned, was divided upon Ramsden's engine. Although in the best modern dividing engines an automatic feature has been incorporated, they in the general principles of their construction are but copies of the invention of Ramsden, which conferred new powers upon science, and a greater refinement of skill upon the fingers of art.

The facility with which the cutters used in the various early gear-cutting machines removed the metal in front of them when in operation, naturally suggested the employment of similar

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was fixed on the face of the block, with a steel hole fixed before it, to bore through; and I had a point that would fall into the holes of the divided hoop; so by cutting shorter, and turning the block less, I got all the numbers on my plate. I need not tell you that you get as many prime numbers as you please; nor that the distance of the holes in the steel chaps must be proportioned to the length of the hoop."

cutters for finishing flat surfaces, and the irregular outlines of a large variety of shapes in metal; but the progress of the idea was exceedingly slow, and in its development for general purposes, mechanicians failed to study carefully the behavior of the cutters of that parent of all milling machines—the gear-cutting engine. This lack of careful reasoning from one use to another resulted in the fact that milling cutters, until very recent years, have been run utterly wrong with a degree of precision most wonderful in its results, but which is not especially creditable to the powers of observation and analysis of those responsible for doing so right a thing in so wrong a way. A boy whittling a stick should have been a good object lesson in this connection. The first milling machine for shaping the surface of metal of which we have any account is illustrated in the French encyclopedia whose publication was completed in 1772. This machine was designed for finishing the exterior of musket barrels, and if properly managed it could not fail to make every barrel of precisely the same shape. Milling machines were designed and used by Eli Whitney for use in manufacturing muskets in the early years of the century, and James Nasmyth introduced the use of milling cutters (rotary files, they were then called) into England in 1829 for finishing hexagonal nuts, and later extended their use to other work. In America the milling machine in its various forms and adaptations, as manufactured by the Brown & Sharpe Manufacturing Co., the Brainard Milling Machine Co., the Pratt & Whitney Manufacturing Co., and many other makers of repute, executes a large proportion of the interchangeable work made. In the manufacture of fire-arms about 40% of the machine tools used are some form of milling machines. Of one well-known and approved type of milling machine, known as the "Lincoln Miller" (originally designed by Mr. F. A. Pratt), it is believed that at least 150,000, or substantial copies thereof, have been sold within the past thirty years.

Although in America the milling machine is perhaps more generally used than in any other country for small work, yet we have been very slow to recognize its great value for the larger purposes for which it has been successfully employed abroad.

Forty-five years ago there was built in England a milling machine for cutting out of the solid metal and finishing at one operation the inside cranks of locomotives. This machine had a

cutting disk 51 inches in diameter, armed with inserted cutters moving at a circumferential speed of 28 feet per minute, with a forward feed of 3½ inches per hour. The width of the cut was 4 inches, its thickness 11 inches, and its length, exclusive of the crank pin, 15 inches. After the throat of the crank was cut out, the forward feed was stopped, and the shaft then given a rotation about the centre of the crank pin, and the whole operation of cutting out the throat and finishing the pin was completed in 9½ hours. Notwithstanding the hints furnished (certainly as early as the year 1702) by the use of circular revolving cutters for the purposes named, the mechanicians of the eighteenth century were many weary years in discovering that the same general ideas so successfully used in metal cutting could be made available in machinery for the working of wood; and it was not until the year 1777, seventy-five years after the first edition of Mr. Bion's work was published in France, and fifty-four years after it had been translated into English,* that the first patent for the construction of circular saws for wood working was issued. This patent was granted to Samuel Miller, of Southampton, England, on August 5, 1777. Among all the workers in wood at that time there appears to have been no one able to transform the revolving cutter—that had been so long used for cutting metal—into the circular saw for the working of wood; and it was reserved for this Miller, a sailmaker, who by no conceivable accident ever used a saw of any kind in his handicraft, to invent what may fairly be regarded as the foundation of all the various rotary devices used in the manufacture of interchangeable articles of wood. In the year 1794 Sir Samuel Bentham, in association with his brother, the famous political economist Jeremy Bentham, established at Queen's Square Place, Westminster, the first manufactory of machines for the working of wood. These premises being soon found too small, No. 19 York Street was also occupied. The extent of the buildings justifies the inference that a large business was carried on. We are told by Professor Willis, in an address before the Society of Arts in 1852, that "there were constructed machines for all general operations in woodwork; including ploughing, moulding, rabbeting, grooving, mortising, and sawing, both in coarse and

* *The Construction and Principal Uses of Mathematical Instruments.* Translated from the French of M. Bion, chief instrument maker to the French King, etc., by Edmund Stone. London, 1723.

fine work, in curved, winding, and transverse directions, shaping wood in complicated forms, and that further, as an example, all parts of a highly finished window-sash were prepared, also all the parts of an ornamental carriage wheel were made, so that *nothing required to be done by hand but to put the component parts together.*" In 1797 the British Admiralty consented to the introduction of Sir Samuel Bentham's wood-working machinery into the dockyards at Portsmouth and Plymouth. This machinery was made under the direction of Jeremy Bentham at the factory before named. That the machinery made by Jeremy Bentham was thoroughly effective, was amply proved by evidence before a government commission which awarded him £23,000 for the right to use it in the prisons and dockyards of the kingdom.

The machines for the shaping of wood that were invented by Sir Samuel Bentham, and carried into practice before the beginning of the present century, were very numerous and important; among them we find an improved rotary planing and moulding machine, a segmental circular saw, conical cutters for dovetailing, an undulating carriage for producing wave mouldings, cutter heads for working two or more sides at once, tubular boring tools, cylinder saws (these, however, had been known as surgical instruments in the time of Hippocrates, 340 years B.C.), reciprocating and rotary mortising machines, bevel and curvilinear saws, rotary cutters for forming screw-threads on wooden screws, and a large variety of other machinery for wood-working. In the year 1799 Sir Samuel Bentham recommended the adoption of the plans of Mark Isambard Brunel for the manufacture of ship blocks by machinery. The Admiralty authorized the construction of the machines, which were completed in 1806; and so efficient was their operation that the first year's saving was computed at £24,000, two-thirds of which was awarded to Brunel for the right to use his ingenious inventions.

It has long been a popular belief that most if not all of the ideas involved in the construction of machinery for the manufacture of interchangeable constructions of wood originated in America; but in view of the remarkable achievements of the Benthams and Brunel, that opinion cannot be successfully defended, and we must take off our hats in acknowledgment of their great originality, and content ourselves with asserting

that we have done mighty work in developing the ideas we have inherited, and that America is the largest employer of wood-working machinery among the nations.

The "Lathe" may safely be accounted the oldest of machine tools. Save that of the husbandman, the tailor, and the art of lying, there is no art older than that of turning; for we are told that Adam and Eve were turned out of Eden, and the first turning tool ever mentioned in history is the flaming sword of the sentinel cherubim, which "turned every way."

It is certain that the potter's wheel, doubtless the parent of all lathes, has been known from the earliest times. Potsherds are mentioned in the Book of Job, and no ruins are so ancient that fragments of the work of the potter are not found therein. The transition from a rotation about a vertical axis to revolution about a horizontal axis, and from shaping a soft mass of clay, with the fingers for turning tools, to the shaping of wood with a tool of iron or steel, seems to us at this day to be very simple and easy; but, judging from the exceedingly slow progress of the development of the art of wood-turning after its discovery, it is pretty safe to assume that several hundred years elapsed after the invention of the potter's wheel before anything like the rudest form of the wood-working lathe became known.

Diodorus Siculus attributes its invention to a nephew of Dædalus, named Talus, about 1240 B. C., but Pliny states that it was first used by Theodore of Samos about 740 B.C., and mentions one Thericles, who rendered himself famous by his dexterity therewith. The ancients employed it for turning a large variety of forms of vases, some of which they enriched with carvings. Centuries afterward, mankind began to perceive that the idea buried in the rotating mud of the potter's wheel could be still further expanded and made useful for the shaping of metals, and at this point in its history the lathe begins to assume importance as a contributor to the art of interchangeable construction.

In 1578 Jacob Bessoni published* at Lyons a remarkable folio containing sixty full-page copper-plate illustrations of a variety of instruments and machines, among which are three engravings of lathes.

One of these contains a suggestion of a guide bar with a ser-

* *Tractarum Instrumentorum Jacobi Bessoni Delphinatis, Mathematici ingeniosissime. Lugduni, Apud Barth Vincentini. Cum privilegio Regis MDLXXVIII.*

pentine groove, and various holes designed to direct and assist in controlling the peculiar hand tool employed. This clumsy machine tool gives us a hint—somewhat feeble, it is true, but still a reminder—that there was a feeling among the mechanicians of that day that some machinery for turning irregular forms was desired, and that they had begun to grope around in the dark realm of studious thought, that vast empire of mechanical possibilities from whence have come to light and life all past inventions, in the hope of discovering some means to satisfy that desire. Another of the plates in Bessoni's work furnishes the first published suggestion for a screw-cutting lathe provided with a guide screw, and the beginning of a slide rest, in means to solidly hold the cutting tool, while the screw being cut was moved longitudinally as it revolved in contact with it. The guide screw, and in fact the whole structure of this lathe, is a crystallization of the uncouth, both in idea and in execution; but, nevertheless, it affords conclusive proof that there was a slowly developing demand for more exact work than had hitherto been possible, and that inventors were endeavoring to satisfy that demand.

The lathes described by Bessoni were all "dead centre" lathes, and the work did not have a continuous rotation, but was alternately revolved by a cord, in a manner similar to a bow drill. This feature seems to have been common to all lathes prior to Bessoni's time. It seems strange that the economy of time and the other advantages of a continuous rotation, as exemplified in the "potter's wheel," were not regarded by the makers of the early lathes.

The royal license and protection granted to Bessoni by Charles IX., of France, for the publication of his invention, was really a royal patent for all the machines described, and therefore Bessoni's book may properly be regarded as the drawings and specifications of this early patent, which, if not the first, is certainly more comprehensive in its scope than any other ever granted to an inventor of machinery.

The license of the king is such a curiosity of brevity and emphasis that it is quite justifiable to quote it entire:

"THE LICENSE OF THE KING.

"By full and special license of the King given to Master Jacques Bessoni, author of this present work, for ten years in the near future, dating from the

day when the work is finished by the printer; all persons of whatever rank or condition, they may be, are prohibited to make, counterfeit, engrave, sell or to consent thereto, even to the drawings for manufacturing, the inventions contained in the present work, without the permission of its author. Upon the penalties contained and specified by said license. Given at Orleans in the year One thousand, five hundred sixty-nine, on the twenty-seventh day of June.

"By the King in Council.

(Signed) "BRULLART."

It may aid the comprehension of the relations of this work of Bessoni to the science of the time, to know that when the above license was granted Copernicus had been dead but twenty-five years. Tycho Brahe was but twenty-three years old; Galileo was in his fifth year; Elizabeth had reigned but ten years in England, and the Pilgrims were not to effect a landing on the "stern and rock-bound coast" of New England until fifty-one years thereafter. Among all the improvements which have combined to make the lathe in its various forms the most important of machine tools for promoting the art of interchangeable construction, the device known as the slide rest is most conspicuous. Like most important inventions, this has more than one claimant.

It is a commonly expressed opinion by writers that the slide rest was invented by Sir Samuel Bentham, as it is clearly described in his patent of 1793; and there is no doubt whatever but that Henry Maudslay made a tool of that kind while in the employ of Joseph Bramah in 1794, which was named by his shopmates "Maudslay's go-cart." Joseph Clement is also deserving of great credit as an improver of the slide rest, in the early part of the present century; but it is certain that the evidence, relative to the ideas embodied in the slide rest, amply justifies the assignment of its origin to France, not only in virtue of the suggestion contained in Bessoni's work already referred to, but more particularly in view of the fact that in the great encyclopedia of Diderot there is an elaborate engraving of a "slide rest" which anticipates anything of the kind claimed to have been made in England by at least twenty years.

The first lathe for cutting metallic screws was devised by some French watchmaker,* early in the last century, for cutting the thread on the fusees of watches. The lathe used is remark-

* *Traité de l'Horlogerie mécanique et pratique.* Par Thiout. Paris, 1741. There are several fusee lathes described in this work; these tools were in use several years before the work was published.—W. F. D.

able for a taper attachment quite similar in its idea and functions to that used in modern tools.

The next step in the direction of the modern screw-cutting lathe was made in 1775 by Jesse Ramsden, who constructed a small lathe for cutting the "endless screw" or "worm" of his "dividing engine." This lathe had "change wheels" and a tool holder on a slide moved by a "lead screw."

In the year 1816, Richard Roberts, of Manchester, invented the modern form of screw-cutting lathe, and in 1830 a Mr. Parsson, of London, invented the swivelling tool post, and in 1831 was awarded the silver medal of the Society of Arts for his ingenuity. Prior to 1828 Joseph Clement invented a surfacing lathe, in which the speed was automatically reduced and the feed automatically regulated as the tool travelled from the centre to the circumference of the work being faced. This lathe was a "gap lathe;" it had flat surfaces for the top of its bed, conical bearings for its main spindle, whose end shake was taken by a pivot set-screw in an oil-tight box, and was provided with a two-speed cone pulley, and a slow speed equivalent to modern "back gear" which could be thrown out at pleasure. It also had a compound "slide rest."

The invention of the "apron" on the front of the "tool carriage," and the idea of attaching the various feed-controlling mechanisms thereto, is believed to have originated with Baxter D. Whitney, of Winchendon, Mass., the well-known inventor of the "gauge lathe," who also devised the first "universal swivelling bearing" for line shafting.

The form of lathe known as the "turret lathe," which has occupied a very important relation to the manufacture of interchangeable mechanisms during the past thirty years, is believed to be of American origin, although no record of any patent can be found, and no one appears to know who designed the first tool of that kind.

So far as ascertained, it seems to have been first made to meet some special emergency, and to have been copied, with more or less variation, from shop to shop, until at last the Robins & Lawrence Co., of Windsor, Vt., at the request of F. W. Howe, made the first machines that were regularly made for sale. Some of these machines were put at work in the factory of the Savage Fire-arms Co. about 1860, and one of the first lot made was purchased by the Brown & Sharpe Manufacturing Co., of

Providence, R. I., and soon after they commenced to make this tool for the market, and were followed by the Pratt & Whitney Co., of Hartford, Conn. The successors of the Robins & Lawrence Co., the Jones & Lamson Machine Co., of Springfield, Vt., and the other eminent firms named, have doubtless built a large majority of the turret lathes thus far sold. This tool has commended itself to all makers of interchangeable mechanism for a large variety of work, and for the special service of manufacturing machine screws it has been made automatic by Sharpe, of Hartford, Conn., and as its capabilities are carefully studied its field of usefulness continues to expand.

Lathes for ornamental turning and the decoration of wood, ivory, and metal, doubtless originated in France. In Bessoni's work (1578) already referred to, there are two "swash lathes" shown, for turning a variety of intoxicated vases and balusters, which were in that day doubtless regarded as ornamental.

A modification of the lathe which has had a very important influence upon the production of interchangeable work is that known as "the Blanchard lathe." This celebrated tool was patented by Thomas Blanchard, January 20, 1820, and his patent was twice renewed, by special act of Congress, for terms of fourteen years, the last renewal being dated January 20, 1848.

If we are to believe all that has been written in commendation of this machine tool, we shall certainly conclude that Blanchard's invention was an original conception, and that it is American genius and inventive talent that the world must thank for an idea that conferred upon mechanism automatic imitative powers that were wholly unknown before. We have not time to discuss all of the evidence of the erroneous character of this view, but we will note a few of its more conspicuous features. As early as 1772, sixteen years before Blanchard was born, we find in the great French encyclopedia an engraving of machinery for turning irregular forms, in which there is a roller operating against a revolving pattern, and controlling the movement of the tool in such a way as to produce on the substance being turned a copy of the outlines of the pattern. In Bourgeron's *L'Art de Tourneur*, published in 1816, we are shown methods of reproducing medallion portraits by automatic machinery, and it is well known that in the latter years of the life of James Watt (died in 1819) he successfully duplicated busts by mechanism of his contriving. In the famous block machinery of Brunel, which

was put in operation in 1806, a revolving cutter was regulated in its action by a profile plate.

Although the invention of Blanchard was not in its chief elements entirely original, nevertheless the combination was sufficiently novel and useful to entitle it to high rank among the more important improvements that have contributed to the perfecting of the art of interchangeable construction.

Grinding machines for the production of flat and cylindrical surfaces by the action of emery or corundum wheels had their origin in America, and have largely augmented the possibility of cheaply producing accurate work in metal. The grinding lathe as perfected by J. Morton Pool in 1868 is believed to have been the first apparatus by which long cylindrical rolls could be given, automatically and at once, an accurate surface and uniform diameter. So delicate is the action of the very simple mechanism employed, that a uniform reduction of diameter of $\frac{1}{20000}$ of an inch is quite within its powers. The invention and successful operation of this admirable tool has made possible the manufacture of widths of paper unknown and unattainable before.

The success, and possibility even, of the various grinding lathes and similar machine tools that have been developed in the past twenty years is due to a very simple American invention—the solid emery or corundum wheel—which has ground its way into recognition and universal employment in all the machine shops of the world.

The modification of the lathe known as the boring machine probably originated in Germany, for in a work published in Nuremberg, 1662,* there is an engraving of a duplex boring mill, operating upon two musket barrels at the same time; and in a treatise on artillery, published in France in 1647,† there is a vignette in which a cannon is shown as being bored by a vertical bar.

About the middle of the last century cannon and pump cylinders, also cylinders for Newcomen engines, were bored horizontally in rude boring mills at Carron Iron-works in Scotland, and in 1769 that celebrated engineer, John Smeaton, designed new boring machinery for these works. It does not ap-

* *Tractarum Machinarum novum et cet.* Per Georgius Andream Bocklerum. 1662.

† *Memoires d'Artillerie.* Par le Sr. Surirey de Saint Remy.

pear that this machinery was perfectly satisfactory, as in a proposal from Boulton & Watt to the Carron Iron Co., in 1776, for the construction of an engine *to return the water to their water-wheels*, Mr. Boulton says: "Mr. Wilkinson has bored us several cylinders almost without error; that of fifty inches diameter, which we have put up at Tipton, does not err the thickness of an old shilling in any part, so you must either improve your method of boring, or we must furnish the cylinders to you." "The thickness of an old shilling" seems to have been regarded as a very satisfactory standard of permissible error in such work one hundred years ago.* The Mr. Wilkinson spoken of by Mr. Boulton was John Wilkinson, of Bersham, near Chester, who had invented improvements in boring machinery in 1775. He it was who first moved a cutter head along a boring bar, supported at each end; and, simple as this idea now seems, it was not perceived by such acute men as Smeaton and Boulton and Watt.

The first planing machine of which we have any account is said by Rennie (Buchanan on Mill-work) to have been invented by Nicholas Torq, a French clockmaker, in 1751, and to have been actually used in planing the interior of the wrought-iron pump barrels used in the machine erected by order of Louis XVI. for the supply of the water-works at Versailles.

We are told that the pumps varied in size from 10 inches to 4 feet in diameter, and were from 7 to 10 feet in length; made of wrought-iron staves, planed on their edges before they were

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* The first account of cylinder boring in America is of the boring of the cylinder for the engine erected at the Centre Square pumping station in Philadelphia, which commenced supplying that city with water on January 27, 1801.

This engine was built by Nicholas Rosevelt, at Soho Works on the Passaic River, New Jersey. The boring of its cylinder—which was 36 inches in diameter and 6 feet 6 inches in length—occupied *nearly four months.*

At that time there were but three other engines in the United States; one an imported engine put up in 1763, by a son of Hornblower, at the "Schuyler Mine" on the Passaic River, New Jersey; one at a sawmill in New York; and a third in Philadelphia, used by Oliver Evans to grind plaster.

The enormous increase of steam power since the beginning of the century is at the same time a measure of and a most prominent reason for the wonderful development of the United States during the last hundred years. In the belief that a knowledge of the total horse-power of the engines now in use in this country would be of interest, I applied to the Census Bureau for information relative thereto, but was very much surprised to learn that the statistics of steam power had not been collected.—W. F. D.

assembled, and confined with encircling wrought-iron hoops 3 inches wide and ½ inch thick. A pump barrel 10 inches in diameter and 7 feet long was made up of 9 staves secured by 12 hoops.

If Rennie's account is correct, M. Torq had a large job for a newly invented machine, of which it is recorded that it did the work in a perfectly satisfactory manner.

I shall not attempt to discuss the question of who was entitled to the credit of first introducing the metal-planing machine into England. Claims have been made for Bramah, Fox, Clement, Murray, Roberts, and possibly some others. There is little doubt that all the persons named constructed, independently of each other, during the thirty years preceding the year 1820, some form of mechanism for planing metal. The best description we have of any of these early planing machines is of one built by Joseph Clement in 1825, as an improvement on one constructed by him prior to 1820. In this machine the bed was 2 feet 8 inches wide and 12 feet long, and was supported upon stationary bearing wheels 2 feet in diameter and 2 inches face. The bed was moved by two pinions working into two racks on its under side. The planer was driven by a belt 3 inches wide, running upon a pulley 4 feet in diameter. This tool was said to be a practical success, and, at the rate of 18 shillings per square foot of surface planed, earned for its owner £10 for each day it was employed.

This machine was no mere experiment, as it is known to have been in regular use in 1863, thirty-eight years after its construction, and nineteen years after the death of its inventor. Another interesting type of planer was built by Benjamin Hicks, of Bolton, about the year 1840.

This was a "pit planer," the piece operated upon being stationary, and the cross head and tool moved by two steel belts 3 inches wide, running on pulleys 3 feet in diameter. This planer could plane a piece of work 30 feet long and 9 feet 6 inches wide.

The style of planer known as the "shaping machine" was invented by the late James Nasmyth (the inventor of the steam hammer) in 1836. It was at first called "Nasmyth's steam arm." It has been greatly improved by Whitworth and other leading tool builders.

The first machine for planing the teeth of wheels, in which

the action of the tool was regulated by a guide curve, was invented, in 1839, by the brothers Glovet.

The vertical planer or "slotting machine" was doubtless suggested by the mortising machine for wood. Machines of this kind were built by J. Nasmyth in 1836. America has done its full share in the development and improvement of construction of machine tools of all kinds, and the work of Wm. Sellers & Co., Bement & Miles, Brown & Sharpe, Pratt & Whitney, the Putnam Machine Co., Niles Tool Works, and scores of other makers of American machinery is known and honored wherever hammers beat and wheels turn.

The art of wire-drawing has been a liberal contributor to the development of the art of interchangeable construction. The making of wire was originally accomplished by beating the metal into thin strips, then shearing it into strands of a more or less square cross section, and then hammering these strands until their angles disappeared and the strands became approximately round.

Until early in the fourteenth century this had been the only method of making wire from remote antiquity, and was probably practised in Egypt in the time of Moses (1450 B.C.), for we are told in Exodus xxxix. 3 that "they did beat the gold into thin plates, and cut it into wires, to work it in the blue, and in the purple, and in the scarlet, and in the fine linen, with cunning work."

This rude method was improved in Germany by the invention of the draw-plate, which was in use at Augsburg as early as 1350. So long as the rounding was accomplished by the hammer, the workmen were called "wire-smiths;" but after the invention of drawing they were named "wire-drawers" or "wire-millers." So slowly did improvement travel in the middle ages, that "wire-drawing" was not introduced into England until about two hundred years after its invention in Germany.

In order to protect and stimulate the manufacture of wire in England, his Majesty King Charles I., in the sixth year of his reign (1631), *absolutely prohibited* the importation of foreign iron wire, and of cards made from the same. This prohibitory act accomplished its intended purpose so well that, eight years thereafter, the king prohibited the importation of brass wire. There is abundant evidence that England's infant industries were carefully nurtured by adequate legal protection.

The relation of wire to interchangeable mechanism is very close ; the manufacture of pins, needles, wire nails, wood-screws, and fish-hooks rests solidly upon a substratum of manufactured wire. English chronicles tell us that " the making of Spanish needles (as the fine sewing-needles were formerly designated) was first taught in England by Elias Crowse, a German, about the eighth year of Queen Elizabeth ; and in Queen Mary's time there was a negro made fine Spanish needles in Cheapside, but would never teach his art to any."

The first stage in the making of the assembling screws of all classes of small machinery is the making of wire.

Wires have been produced, by a combination of mechanical and chemical operations, of a fineness of $\frac{1}{50000}$ of an inch, and so smooth and uniform as to rival the spider's web, for use in micrometers and similar instruments. The process of wire-drawing is not confined to products of a circular cross section, and a great variety of shapes have been made ; but the most interesting form is doubtless that known as " pinion wire," from which the pinions and arbors used in watches were for many years made. Pinion wire was also used in the beginning of the century in the construction of clocks. The preparation of wheels and pinions for clockmakers' use seems to have been at that time a distinct industry, for in Rees's *Encyclopedia* (1819) we are told that " ironmongers and tool sellers have on sale sets of wheels and arbors with pinions of different numbers ready slit, and also pinion steel wire drawn in proper shape for the teeth of small pinions, of which all clockmakers usually avail themselves, instead of preparing them." Thus early does the interchangeability of the parts of clocks manifest itself.

Another application of the principle of wire-drawing was originally introduced in the British mint by Sir John Barton, for equalizing the thickness of the " fillets " of gold and silver from which the blanks for the coin were cut. This consists in drawing the " fillet " (after it has been nearly reduced to the proper thickness by rolls) between stationary hardened steel cylinders, one of which is adjustable by mechanism which enables $\frac{1}{100000}$ of an inch to be readily appreciated.

The art of drawing tubes of metal through fixed dies is a natural outgrowth of the art of wire-drawing; and a further development of this art is exemplified by the manufacture of metallic cartridges, in which we have an admirable illustration

of one of the most recent and most important developments of the art of interchangeable construction.

The art of making a cartridge shell of sheet metal originated in France. In the year 1824 M. Cazalet patented a cartridge of this material; and in 1834 M. Roberts, of Paris, invented a metallic cartridge in which the fulminate was deposited in an annulus around its base, which was made of a separate piece of metal from the body of the cartridge. The idea of using a metallic cartridge did not attract much attention until M. Flobert, about 1850, commenced the manufacture of a pistol intended for use for practice at short range. This pistol could only use a small metallic cartridge, charged exclusively with fulminate. Flobert's pistol and ammunition met with considerable favor for its purpose, and doubtless it had a stimulating influence upon the development of the manufacture of metallic cartridges of an improved type.

To Smith & Wesson, of Springfield, Mass., without doubt belongs the credit of making the first metallic cartridge suited to the requirements of actual service in war. In 1854 they patented a form of cartridge that has always been used in the well-known pistol made by this firm.

Since the above date, the idea has been adapted to breech-loading muskets of a large variety of styles, and at the present time metallic cartridges are made for quick-firing guns of 3-inch calibre.

It is believed that the general system adopted in the manufacture of the modern metallic cartridge is purely American.

The rapidity, accuracy, and economy with which they are manufactured is the result of the perfecting of a large number of special automatic machines, whose work is so exact that any cartridge will fit accurately—that is, will never be too large for, and never more than $\frac{1}{1000}$ of an inch smaller than, the chamber of the arm in which it is intended to be fired.

The Union Metallic Cartridge Co., of Bridgeport, Conn., which for thirty years was under the skilful management of the late A. C. Hobbs, has been the leader in the development of this industry, and has supplied the principal foreign governments with large quantities of ammunition and cartridge-making machinery; and it is only just to say that the system of manufacturing metallic cartridges, now regarded as the best throughout the world, was brought to its present state of per-

fection in these works during their administration by Mr. Hobbs.

The art of cold punching of sheet metal has important collateral relations to the art of interchangeable construction. Perhaps the best exemplification of the art of punching is furnished by the gold and silver blanks which are punched in the several mints of the world for subsequent coining into money. The weight of these blanks must be uniform for the specific coin for which they are intended, and this can only be insured by extraordinary care in the making of the punches and dies. The flat links of the chains used in the old fusee watches were punched as early as the middle of the last century.

The punch was made of the same contour as the link, and was guided in its work by two conical pins projecting from its face ; these pins entered the holes, intended for the rivets, which had previously been punched in the sheet steel from which the links were to be made. The metal was thus guided to its proper position on the die, so that when the punch took effect, the exterior of the resulting link was symmetrical with regard to the rivet holes through it. This principle thus early discovered is of frequent application in all similar operations. The art of punching has, in comparatively recent times, had coupled with it the art of shaping the metal blank into various forms immediately after the punching operation is completed; boxes and their covers, "percussion caps," the cups for metallic cartridges, and the metal bases of shot shells are made in this way.

The art of interchangeable construction was strongly reinforced by the discovery of the method of forging in dies. This idea was but an application of the art of coining cold metal, for use in money (which had been known since the time of Darius, 500 years B.C.), to the shaping of metal while hot. The art of forging in dies is believed to have originated in France about the middle of the twelfth century; and numerous examples of hinges, grills, and wrought-iron ornaments of various kinds remain as elegant testimonials to the cultivated taste and wonderful skill of these ancient artists in iron. Forged ornaments shaped by dies were common on all the pleasure carriages made in the last century; and it is certain that the wonderful "one-horse shay" would not have been the masterpiece it was, if its "step-irons" had not been decorated with "swaged" ornaments.

It seems but a very short step indeed from the forging of ornamental iron work in dies, to the forging of the smaller parts of machinery in the same way; but as short as it undoubtedly was, it does not appear that it was taken until the late Albert Eames introduced the practice of forging parts of muskets and pistols in "dies or swages," at Chicopee, Mass., in 1842.

One more step forward in the art of forging the parts of interchangeable mechanisms brings us to what is known as "drop forging." This art is believed to be of American origin, and was first used at Harper's Ferry, Md., in the year 1827, in the works of J. H. Hall. An improved form of drop-forging machine was made by the late Albert Eames for the Remington works at Ilion, N. Y., in 1846. From this date the use of the process of drop forging has rapidly increased, and it has been applied to the manufacture of very intricate as well as delicate articles. The Billings & Spencer Co., of Hartford, have for the past twenty-five years turned out annually large numbers of shuttles for sewing-machines, so nearly exact to size as to require little work and polishing to render them fit for their intended service. The art of drop forging is also used for producing the heavier parts of bicycles, and for an endless variety of forgings in iron, steel, and copper, forging of the latter metal having come into use for electrical machinery within the last eight years. So important has the art of drop forging become as a factor in manufacturing, that at the present time no establishment for the manufacture of interchangeable mechanism, of which forgings are a component part, can afford to ignore its advantages. In the making of drop forgings the preparation of the dies is a matter of the first importance, and so high has American skill in this particular been appreciated abroad, that from time to time, large numbers of finished dies have been sent from America to foreign countries. The Billings & Spencer Co., of Hartford, Conn., who are pioneers in the art of drop forging, shipped at one time forty-two tons of dies to Prussia, for the making of forgings for the parts of muskets.

The economical production of interchangeability in mechanism necessitated instruments for rapid and accurate measurement. These were slowly supplied. The invention of the micrometer by William Gascoigne, of Yorkshire, England, about the year 1637, at once placed in the hands of science the power of measuring to a degree of minuteness unknown before. Gascoigne

was killed, when thirty-two years of age, at the battle of Marston Moor, on the 2d of July, 1644, while fighting for his king. The principle of Gascoigne's micrometer consisted in moving two parallel edges or pointers to or from each other by means of a screw provided with a divided head. Dr. Robert Hook proposed to use in this micrometer parallel wires or hairs; but with such slow, hesitating steps did improvement move in the days of the youth of the micrometer, that it was not until 1755, more than one hundred years after its birth, that the first suggestion of the use of spider webs therein was made by Prof. Felice Fontana, of Florence, and it was not until John Troughton's attention was called to the matter by David Rittenhouse, of Philadelphia, that it was carried into practice in 1788, the idea, curiously enough, reaching England by way of America. There is no certainty that Rittenhouse had ever heard of Professor Fontana's suggestion, but before calling Troughton's attention to the value of the spider lines for micrometers, he had already used them himself in the fixed diaphragm of a transit instrument. Since the application of the spider lines to the micrometer, this instrument has received endless modifications. to adapt it to special service, from the hands of some of the ablest scientists and mechanicians of Europe and America, Neither my allotted time nor your patience will permit a description of what has been accomplished in the invention of special types of this instrument; but a brief account of the origin of the micrometer caliper, now so commonly used by the best workmen all over our land, may be of interest. It appears that the first of this form of caliper used in America was made in the year 1867, in the machine shop of the Bridgeport Brass Co, at Bridgeport, Conn., from sketches furnished by S. R. Wilmot, who at that time was superintendent of that company. This instrument was made to measure in thousandths of an inch, the thickness of sheet brass then being rolled for the Union Metallic Cartridge Co., to use for the manufacture of cartridges.

The requirements of the late A. C. Hobbs, then the superintendent of the cartridge works, had so narrow limits of variation, that some more accurate means of measurement than the ordinary wire gauge was required to regulate the rolling. This is doubtless the first instance in which common sense asserted itself successfully against more than a century of rolling mill prac-

tice, in determining the thickness of sheet metal, and it deserves to be regarded as the initial step in the movement that promises ere long to consign all *wire gauges* to the tomb of defunct mechanical expedients.

It is also in evidence that a representative of the Brown & Sharpe Manufacturing Co., of Providence, R. I., saw at the Paris Exposition in 1867 an instrument of similar form and purpose to that made by Mr. Wilmot, save that the French instrument had a revolving scale attached to its screw. This instrument was invented in 1848 by Jean Laurent Palmer, a machinist of Paris, and was duly patented in France on September 7th of that year. The Brown & Sharpe Manufacturing Co. commenced the manufacture of this form of "micrometer caliper" in the latter months of 1867, and from the time it was put on the market by them (1868), its use has rapidly extended; but there is no small amount of humiliating interest in the fact that it was *nineteen years* after the publication of the invention of Mr. Palmer, in France, before the mechanics of America discovered the value of this very convenient tool.

The discovery, by the late Sir Joseph Whitworth, of a way to produce plane surfaces on metal by "scraping," has had a marked influence in increasing the accuracy of work intended to be interchangeable, and so accurate have surfaces been made by the method, described in a paper read by him before the Institute of Mechanical Engineers, at Glasgow, in 1856, that it has been demonstrated that when two such surfaces are placed in contact it requires more force to separate them than the equivalent of the pressure of the atmosphere upon them, thus showing that the surfaces were approaching the condition of actual molecular cohesion.

Thus far I have discoursed of the development of methods and apparatus which have rendered possible the art of interchangeable construction as it is understood to-day, and have had little to say of special industries whose products are representatives of the degree of perfection to which the art has attained.

When the idea of interchangeability was first promulgated, it was advocated with special reference to the manufacture of muskets, and it is a common belief that the idea of making the parts of muskets interchangeable originated in America; but the facts of history compel us to say that this view is not correct.

Thomas Jefferson, writing from Paris to John Jay, under date May 30, 1785, says:

"An improvement is made here in the construction of muskets, which it may be interesting to Congress to know, should they at any time propose to procure any.

"It consists in the making of every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the magazine.

"The government here has examined and approved the method, and is establishing a large manufactory for the purpose of putting it into execution.

"As yet the inventor has only completed the lock of the musket on this plan; he will proceed immediately to have the barrel, stock and other parts executed in the same way. Supposing it might be useful in the United States, I went to the workman. He presented me the parts of fifty locks, taken to pieces, and arranged in compartments. I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantages of this when arms are out of repair, are evident. He effects it by tools of his own contrivance, which, at the same time, abridge the work, so that he thinks he shall be able to furnish the musket two livres cheaper than the common price. But it will be two or three years before he will be able to furnish any quantity. I mention it now, as it may have an influence in the plan for furnishing our magazines with this arm."—(*The Writings of Thomas Jefferson*, edited by H. A. Washington, 1853.)

On January 24, 1786, Mr. Jefferson writes a similar letter to the governor of Virginia, in which he is even more emphatic in regard to the gun locks he has examined, saying that "I found them to fit interchangeably in the most perfect manner."

In the year 1798, thirteen years after Jefferson had found that gun locks were manufactured in France which "interchanged in the most perfect manner," Eli Whitney, the inventor of the saw cotton-gin, contracted with the United States to furnish them with ten thousand stand of arms. In regard to this work, his biographer says: * "The object at which he aimed, and which he fully accomplished, was to make the same part of different muskets, as the locks, for example, as much like each other as the successive impressions of a copper-plate engraving." This was a very high standard; and Mr. Whitney struggled energetically against all sorts of difficulties, and doubtless realized to some considerable degree his intention of making the parts of the muskets interchangeable, and is entitled to great credit for the pioneer work in the art of interchangeable construction which he accomplished, and the large measure of success which he achieved in carrying out, with the limited resources available in

* *Memoir of Eli Whitney, Esq.*, by Denison Olmstead, 1886.

America at the time, the idea which Thomas Jefferson stated, thirteen years before the date of Mr. Whitney's contract, was being prosecuted successfully in France.

Looking backward at the art of interchangeable construction as exemplified in the work done at the beginning of the century, and viewing it in the light of the exact requirements of to-day, it is certain that very little of the work done at that time would pass inspection now; most of the parts of the old muskets would doubtless interchange, but the exactness of the relations of the parts would not be found up to present standards. The demand for such precision was not made, and could not, with the means at command, have been realized if it had been insisted upon. Even the mechanical means of attaining interchangeability in some of the parts of muskets were not invented until 1853.

As a consequence of the pioneer work of Eli Whitney, and the enthusiastic zeal with which the path he blazed through unknown regions has been followed, widened, and extended by multitudes of ingenious and skilful mechanicians, America has become the great school of the world for all who are seeking instruction in the art of interchangeable construction. As the result of the excellent work on a small exhibit of rifles by Robins & Lawrence, of Windsor, Vt., at the International Exposition of 1851 in London, the British government sent a commission to America to study the methods of manufacture by which interchangeable construction was attained.

This commission visited Springfield Arsenal and a number of other public and private armories, and as a result they at once ordered a large quantity of American gun-making machinery, and secured the services of a number of American mechanicians to accompany it to England, and there establish the Enfield rifle factory, the first in Europe in which arms were made on the American interchangeable system.

As an illustration of the perfection which this system had attained when the English commission visited Springfield Armory, in 1853. Major Ripley, who was then in command there, ordered ten guns, manufactured from 1843 to 1853, to be taken apart, the parts indiscriminately mixed, and the ten guns were then successfully assembled by selecting the parts at random from the general mass.

Since the year 1853, American gun-making machinery has

been supplied to the governments of England, Spain, Prussia, Sweden, Russia, Denmark, and Egypt; and large quantities of American arms and ammunition have been shipped to all quarters of the world. So manifest were the manifold advantages of the system of interchangeable construction as applied to the manufacture of arms, that it has been extended to a great variety of other industries, in which large numbers of the same kind of product are produced—locks, sewing-machines, steam valves, steam engines, hardware, and agricultural implements, clocks and watches. The idea of manufacturing watches by the interchangeable plan is distinctly American, and was first carried into effect on a large scale at Waltham, Mass., in 1854. Since that date watch factories have increased and multiplied in the land, and foreign nations have been compelled by American competition to adopt the idea which is the crowning triumph of the American system of interchangeable construction.

In the foregoing outline of the development of those arts which are distinctly tributary to the art of interchangeable construction, I have endeavored to show that the idea of interchangeability in the construction of mechanism is of no recent origin—that in fact, if not in name, the commencement of its practical development was coeval with the satisfaction of the most primitive of the artificial demands of man upon the materials of the world in which he found himself placed; that as mankind increased, and multiplied his requirements of nature, the elements from which to create the art of interchangeable construction were necessarily augmented by the discovery of new methods and the invention of apparatus for their utilization; that this process of mental demand and material supply changed gradually from the simple and easy to the complex and difficult; but, nevertheless, every demand within what we have been irreverently taught to call the laws of nature has been successfully met by the crystallization in its work of enough of the immortal soul of each succeeding generation to enable the world of our day to enjoy the usufruct of the labors of all time past, and to rejoice in the practical perfection to which the art of interchangeable construction has attained.

Contemplating the magnitude of past achievements; realizing the vast power which the concentration of the inspired thought and best work of all ages have placed at our disposal; perceiving, as "through a glass, darkly," a suggestion of the manifold glories

of that future which will be the living present of some unknown generation, we seem to see Science in command of a grand ship called Art, fully rigged, manned, and equipped for a voyage of unknown length, its prow pointed westward, as with adventurous keel, flowing sails, and a crowning glory of flags, pennons, and streamers, it speeds over the uncharted waters of the ocean of time toward undiscovered shores. As we view the picture and reflect upon the persistent faith that has guided the noble vessel to the discovery of fair islands and grand continents in time past, the mind naturally reverts to the voyage of that great discoverer in whose name we have erected these temples and invited all lands to do him honor by offerings of "gold and silver, frankincense and myrrh."

It is by such persistence as his, in following the directing compass of an o'ermastering faith, that Science and its argosy will make discoveries of new lands under skies and stars to us unknown. On such a voyage Science will permit of Art no suggestion of turning, and when Doubt shakes its skeptical head, and Fear asks timorous questions, the reply of Science will be as sternly decisive as was that of Columbus, when—

"Behind him lay the gray Azores,
Behind, the gates of Hercules;
Before him only ghosts of shores,
Before him only shoreless seas.
The good mate said, 'What shall I say
If we sight naught but seas at dawn?'
'Why, you shall say at break of day,
Sail on—sail on—sail on—and on!'" *

* Joaquin Miller.

DL.

REPORT OF COMMITTEE ON STANDARD TESTS AND METHODS OF TESTING MATERIALS.

PRESENTED AT THE ENGINEERING CONGRESS, CHICAGO, AUGUST 1, 1893.

As the study of the subject intrusted to this Committee is one undergoing constant enlargement, and the subject itself is being rapidly developed in many countries, it was thought most advantageous to follow its development and its literature and present those facts which have been elaborated since the last report.

The investigations necessary to arrive at definite conclusions in regard to the value, accuracy, or propriety of methods proposed for determining qualities of material, must necessarily be so costly and elaborate, that your Committee, without funds and without the means and time at their disposal, have decided to devote their entire attention to presenting to the Society, from time to time, such matters, properly edited and arranged, as may be brought to their notice, the correctness of which has been developed and demonstrated at home or abroad. For this purpose and with the sanction of the Society, the reporter of this Committee attended the conference at Vienna, May 23–25, 1893, and he has transcribed the conclusions arrived at or resolutions adopted, which are herewith presented as Appendix V. to the report of the Committee.

This Appendix V. is to take the place of the original report and Appendix II., in which a number of modifications must be made in order to make it in agreement with facts developed since the presentation of the report and to make it more complete. It will be noticed that the principal differences consist in rules for bending tests, for tests of boiler plate, for tests of copper, and also for tiles, and finally the recommendation of a standard length of test piece, developed from the proven relation of length and cross-section of test piece on results.

This latter makes the results largely independent of the shape,

provided the proportions have been adhered to, and makes tests comparable.

Repeated conferences in Europe, attended by representatives of all countries except England, have helped to simplify testing and inspection materially, and have also cheapened the production and delivery of materials, besides avoiding delays caused by misunderstanding instructions. There is no doubt that the study of the work of these conferences, as well as of that of the French official commission appointed to study the subject, would have a very satisfactory result in our own country; there can be no doubt that the great variety of specifications now used in the United States would be much reduced and simplified, to the great advantage of our manufacturers as well as consumers, and many discussions would be avoided. The results obtained by the repeated meeting of the German conferences have no doubt been the primary cause which led French engineers to advise their Government to appoint an official commission, which has delegated a representative to attend the deliberations of this section. The Vienna conference has also delegated a representative to this meeting in order to further the work and interest which all engineers and manufacturers have in common, and for the distinct purpose of urging the inauguration of conferences having a truly international character. As the interests participating become more varied, the results will become of greater value and importance; and for these reasons your Committee recommend that steps be taken to have the Society represented at these conferences, and to urge upon the proper authorities of our Government to send representatives whose duty it shall be to make full reports of the proceedings.

Through the efforts of the Committee copies of all of the publications containing the investigations on which the Vienna and previous conferences based their resolutions, will be embodied in the library of the Society, for future reference, but it is regretted that the necessary time for making translations of all of them is not available.

The character of the proposed conferences is to be purely deliberative, and its resolutions never mandatory. Their importance and influence will be a matter of necessity, being the voluntary expression of opinion of engineers and manufacturers who are most deeply interested in establishing correct and reliable

standards. In view of the foregoing explanations the Committee desires to offer the following

RESOLUTION :

Whereas, The American Society of Mechanical Engineers consider it to be of the greatest importance that its members be constantly informed of the latest developments and additions to methods of testing materials ; and,

Whereas, This can only become a fact by the constant interchange of opinions by engineers and manufacturers of all countries ; therefore,

Be it resolved, That the American Society of Mechanical Engineers urge the inauguration of International Conferences for the unification of methods of testing, and also urge our government to take cognizance of such conferences by sending duly accredited representatives.

R. H. THURSTON,
H. R. TOWNE,
CHAS. H. MORGAN,
THOS. EGLESTON,
GUS. C. HENNING,
} *Committee.*

*Prof. A. Martens.**—I gladly avail myself of the permission to speak in German, as I do not feel equal to making myself understood in English.

To begin with, I should like to add a few historical notes to the remarks of Professor Debray and Mr. Henning. Professor Debray reported what steps had been taken in France toward introduction of unification of methods of testing ; Mr. Henning reported about our German efforts and presented the results of our latest deliberations in Vienna, at which he participated as your representative. The French efforts received their first recognition by the Paris congress in 1889.

Our German opinions about the unification of methods of testing received their first expression in the conference called by Professor Bauschinger in Munich in 1884. It is hardly necessary to call your attention to the results of our deliberations, as you have watched and followed our efforts from their beginning and have had the adopted resolutions translated into English. But I should here like to touch upon one point, namely, that the voice of America has not been without influence on our German work, although it has but this year taken immediate part in our deliberations. It was Professor Egleston who —I cannot now remember whether of his own accord or on your instructions—gave Professor Bauschinger and myself encourage-

* Of Berlin. Director Royal Prussian Testing Laboratory, at Charlottenburg.

ment in 1884, by correspondence, which imparted to our German conferences a material impetus. Our conferences, to our great pleasure, have assumed a more or less international character, and we saw with considerable satisfaction that France also, by deputing Professor Debray and M. Candlot, and finally your own country, by sending Mr. Henning, took active part in our work. We hope that we shall also work together in the future.

We have followed the work in other countries with interest, and are especially pleased to note that the principles which we laid down in our first conference have also been adhered to in France, and in such a degree that they were adopted in their entirety in the preliminary official steps taken with a view to establish a French national commission.

With the very able coöperation which we have found in many countries, as well as in America, we may be permitted to hope that testing materials may soon conform everywhere to standard principles, in its essential parts, so that we will be finally enabled to consider all results of tests to be of equal value, and comparable, and thereby to constantly broaden the basis of our scientific knowledge.

DLI.

APPENDIX V.

TO THE

REPORT OF THE COMMITTEE ON STANDARD TESTS AND METHODS OF TESTING MATERIALS,

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

This Appendix contains the results of the deliberations of the several international conferences, at the last of which the reporter was present as delegate of the Society.

G. C. HENNING,
Reporter for the Committee.

RESOLUTIONS OF THE CONFERENCES

HELD AT

MUNICH, DRESDEN, BERLIN, AND VIENNA

RELATIVE TO

UNIFORM METHODS OF PROCEDURE

IN

TESTING BUILDING AND STRUCTURAL MATERIALS,

TO DETERMINE THEIR MECHANICAL PROPERTIES; COLLATED BY ORDER OF THE CONFERENCE AT VIENNA

BY

PROF. J. BAUSCHINGER,
Professor at the Technical High School at Munich.

TRANSLATED BY GUS C. HENNING, M. E.,
Reporter to Special Committee on Standard Tests and Methods of Testing Materials, A. S. M. E.

1893.

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INTRODUCTION.

It is hardly necessary at this day to furnish proofs that tests of the resistance of materials can only be compared when they have been made according to a uniform standard method.

Even the standard rules for furnishing and testing Portland cements, which were established by the association of German cement manufacturers as long ago as 1876, resulted from the perception that such agreement was necessary. Likewise the specifications for furnishing axles, tires and rails of Bessemer metal and steel, which were proposed in 1879 by the general convention of the association of railway managers of Germany, advising their adoption by the managers of the association.* But these first steps to establish standard methods of testing emanated from quarters which from their nature included only technical specialists; on the one hand, purely manufacturers, and on the other, purely consumers; and although, in establishing these standards or norms, it was sought to make them as unprejudiced as possible, particular interests predominated, and this was urged against them on behalf of the opposite party.

Moreover, these deliberations related to one group of materials alone, and were not confined entirely to methods of testing, but also established requirements which these materials must fulfil when tested by the prescribed methods. For this reason it was certainly an apposite undertaking when, in the autumn of 1884, professional men of the most varied technical callings assembled at Munich, to attempt to formulate uniform methods of testing of all of the more important materials of construction, which were to be limited to *methods of testing*, neglecting entirely the requirements which different materials had to fulfil.

Eventually, a number of important questions were agreed upon; certain others were referred to a standing committee, which, later, considered them primarily by letter, and discussed

* The properties of iron and steel, VIII. Supplementary volume of the publications of the progress of railway construction. Wiesbaden, 1880.

them orally,* later on, at two meetings held at Munich, 21st and 22d of September, 1885; finally, the results and conclusions were presented at the second general conference held at Dresden, September 20 and 21, 1886. The latter concurred in most of the conclusions presented; but there still remained a number of unsolved problems, which again were intrusted to a second standing committee, whose duty it should be to discuss them and then present their findings to a third conference which met at Berlin, September 19 and 20, 1890, and at which a part of the problems were solved; the others, increased by new ones suggested by further study, were again returned to the standing committee, which was to report on them at the fourth conference to meet at Vienna. This last conference met on May 24 and 25 of this year, but again only some of the problems were considered solved, while the others, besides additional new ones, were turned over to a fourth standing committee for further study and deliberations. It was also decided that the chairman of this committee be authorized to issue a corrected and complete memorial, containing all the resolutions of the several conferences, similar to that issued in 1887.

The hope expressed in that memoir, that it "might keep alive the interest in the work of the conferences, and might create it in such quarters as had kept out of touch with them," has been most fully realized.

Not only was the number of representatives from countries already interested considerably augmented (Germany, Austria-Hungary, Switzerland, Russia), but other countries (France, the United States, Norway, Holland, Italy, Belgium, and Spain) also sent engineers, so that the conferences have assumed a truly international character.

To further improve the growth of these conferences, we deem it necessary to state that each conference is a voluntary convention of men assembled for a free exchange of opinions upon the best methods or systems of testing particular materials, which are to serve certain purposes. If resolutions are voted at these conferences, they can only decide which method of procedure is considered the best by the *majority* of those present.

* The detailed report giving the transactions of the conference at Munich, and the constitution of its standing committee are contained in the XIVth part of "Mittheilungen aus dem mechanisch-technischen Laboratorium der technischen Hochschule München." Munich, Theo. Ackermann.

According to the first resolution of the first conference "the discussions are to be free, and the resolutions not binding." There are no obstacles to a subsequent conference resuming a question which had been decided by a previous one, in order to be again discussed and voted upon. Methods of testing cannot remain the same; they *must be developed in accordance with our increasing knowledge of the properties of materials used in construction*: with the improvements made in their production; with the adoption of new materials for the same, etc., etc., etc.

It, therefore, becomes necessary that those who take interest in testing materials, from a scientific standpoint, or because they are manufacturers or consumers, assemble from time to time, in order to deliberate afresh, exchange opinions, and to mutually learn and teach, and then as a result of their deliberations agree upon methods of testing which are by them, or at the least by the majority, considered the most satisfactory to be adopted for the time being.

The close relations existing between all civilized industrial countries, generated by constant intercommunication, would make the resolutions of such conferences of little value if they were the expression of opinions of engineers in a few countries only; but the necessity of their *international* character made itself felt, and hence created the international development of these conferences, which were originally limited to Germany and a few of the neighboring states.

By a presidential decree in France, dated November 9, 1891, a "*Commission des méthodes d'essai des matériaux de constructions*" was created, having the same object as that pursued and developed by the conferences of Munich, Dresden, Berlin, and Vienna, and their standing committees. Unquestionably such official establishments have two distinct advantages over voluntary conferences: (1) they have greater authority, at least in their own country; and (2) control funds for extended series of special investigations, which may become necessary. They, however, lose their international character, which must be rehabilitated by some relation between the different governmental commissions, but they would certainly lose those qualities, emphasized above, which are characteristic of voluntary conferences. The above advantages could, however, be preserved if the standing committees, working during the intervals between such conferences, were composed of voluntary industrial representatives, as well

as delegates of technical departments, authorities, societies, etc., etc.

After such discussion, the chairman of the fourth standing committee was instructed to make all possible effort to secure the appointment of the greatest number of delegates on this committee, from governmental technical departments, societies, etc.

In the following collation the resolutions already adopted are printed in ordinary type, their causation in small type, while those questions referred to the standing committee, as well as the unsolved problems, are in italics.

I. GENERAL RECOMMENDATIONS.

1. Every *testing machine* must be so arranged that it can be readily and accurately tested or rated.

The construction thereof must be such that when properly operated all *impact* due to loading is avoided.

This property appertains as well to hydraulic as to screw machines.

For practical purposes an arrangement for making the machine work automatically is not necessary.

2. Good *shackles* or *holders* must be so constructed that the tension or pressure be distributed as uniformly as possible over the cross section of the test piece.

Therefore the requirements:

α, for Compression Tests:

a. Free and easiest possible motion of one of the tables or supports in all directions.

b. The surfaces on which the pressure is applied must be as nearly as possible parallel, and for this end they must be planed or turned when the material permits it.

β, for Tension Tests:

Free and easy movement of the test piece for adjustment at the beginning of test. These conditions are fulfilled according to experience.

For *round rods* by the ball bearing, most satisfactorily such with undivided spherical shell.

For *flat bars*, pinhole with pin, and with one hole and bolt at each end only, or milled ends and corresponding wedges.

The use of serrated wedges, *i. e.*, of such steel wedges as force themselves into the test piece, are to be discarded.

3. Any one *standard* form of machine for testing, in daily practice, cannot be recommended; it is, however, to be mentioned that a number of the well-known apparatuses answer their particular purposes more or less perfectly.

4. To the results published by the experimenter are always to be annexed such short notes upon the machines and methods employed as are necessary in judging of the value of the results obtained.

5. To the results of tests obtained are to be added, whenever possible, in addition to the source of the test piece, a microscopic or chemical examination, or both, as well as notes on the process of manufacture of the test piece, and other physical, chemical, or technical characteristics.

Such amplification of the results of tests will rarely be possible in *routine testing;* it is, however, highly desirable, and never to be neglected in scientific researches.

6. In reference to the necessary and sufficient accuracy of testing machines, instruments, and results of observations of tests, the following is to be noted:

a. In view of rapid and practical testing it is recommended that the attempted accuracy of measurements of power and of deformation does not pass beyond unavoidable errors and imperfections of materials.

b. For scientific tests it is unquestionably imperative to strive to obtain the highest degree of accuracy.

c. It is most urgently desirable, when publishing results of tests, to state the degree of accuracy obtained, or at least to give data which will serve to form a correct opinion of the same. In accordance with knowledge thus far obtained it is permissible to add the following clause:

d. It is sufficiently accurate—taking for granted that standard test pieces as described below (see II. *M*, and IV. *b* and *c*, pp. 1283 and 1288) have been used—to note in case of metals:

For loads at yield point or maximum of tenacity, the nearest 100 lbs. per square inch, while ultimate elongations are to be noted to the nearest tenth per cent., and reduction of area is to be given to the nearest per cent.

The last figures are as a rule inaccurate, and it is useless to add more figures. In order to obtain this degree of accuracy it becomes necessary to make all measurements of shape accurate to the nearest $\frac{1}{250}$ inch.

7. The influence of time on the results of tests of materials, according to Fischer and Hartig, cannot be doubted. Later investigations have demonstrated that there is no necessity to maintain a certain uniform rate of elongation when testing the principal materials of construction; *i. e.*, iron and steel, copper and bronze. (See Bauschinger's tests, Vol. XX. of his "Mittheilungen," etc.)

8. The materials are to be tested for those qualities or properties for which they are adopted in construction.

The quality of a material itself is the resultant of all of its mechanical properties. As long as the interdependence of these several properties is unknown, so that the existence of several might lead to the determination of others—and we are still far from that point—so long the observation of a few of the properties will not be sufficient to judge of the applicability of the materials for different purposes, and they must be tested for those properties for which they are adopted in construction.*

9. Those materials which are acted upon by *percussion* or shock in structures are to be tested by *drop tests*, in order to determine their character.

10. The drop tests are to be made by means of a *standard* "*drop.*" For such the following essentials were adopted:

a. It was not considered advisable to adopt the complete design of a standard "drop," but accurate requirements are to be exacted for those details which can influence the results of tests. It is recommended that the frame of the drop be constructed of iron or steel.

It was thought necessary to bear in mind those existing "drops," which for the most part conform in their essential parts to the following requirements.

b. Every "drop" is to be standardized.

It is not impossible that drops, which had been constructed with all possible care, give erroneous results, affected by unavoidable influences.

c. In conformity with custom of German railroads, and in consideration of the fact that "drops" are generally erected and used indoors, the weight dropped is fixed at 2,205 pounds (1,000 kilos); in special cases only 1,102 pounds (500 kilos) may be used.

d. The weight may be made of cast iron, cast or wrought

* The detailed discussion of this decision is given in Part XIV. of the "Mittheilungen," etc., pp. 156-160.

steel; the shape is to be such as to place its centre of gravity as low as possible.

The face of the weight is to be made of forged steel, and to be placed accurately symmetrical to the vertical axis through the centre of gravity of the weight by dovetail and wedges. Special marks are to indicate the accuracy in this respect.

The vertical line through the centre of gravity of the weight must be central to the guides. Special marks on the anvil are to indicate this centre line.

e. The length of the guides on the weight shall be greater than twice the clear width between the guides.

The guides are to be made of metal, *i. e.*, rails, and to be so constructed that the weight has very little play. Greasing the guides with graphite is recommended.

f. "Drops" are to have an appliance which permits raising the weight to any definite height, accurately. Detachment or release must not produce oscillation of the weight between the guides, and, therefore, the escapement must be easily and freely controllable. The point of suspension must be truly above the centre of gravity of the weight. Between escapement and the weight there is to be a short movable link; *i. e.*, chain or rope. The method officially employed in Russia is particularly recommended, as shown in Fig. 455.

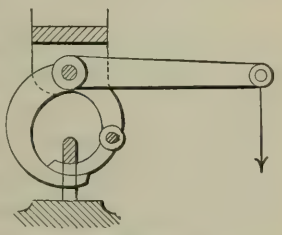

Fig. 455.

g. With constant height of fall, an automatic detaching device is recommended.

h. The bearings for the test piece are to be rigidly attached to the scaffold or frame; *i. e.*, to be wedged fast.

The bearing blocks should always be as nearly as possible in one piece with the scaffold or frame.

i. The weight of the frame and anvil block shall be at least ten times that of the drop weight.

Inasmuch as tests with the ballistic drop and with an ordinary drop which had a weight of anvil of only four times that of the weight gave sufficiently corresponding results (see Kick "On the Law of Proportional Resistances"), it may be confidently assumed that with a tenfold weight of frame and anvil block the results will invariably be comparable.

k. The foundation shall be inelastic and consist of masonry, the magnitude of which should be determined by the locality and sub-soil.

l. The surface struck should always be level; therefore, proper shoes or bearing blocks are to be attached when testing rails, axles, tires, springs, etc., etc., to provide an upper flat surface. These blocks are to be as light as possible.

A uniform drop weight with flat surface of contact is recommended in order to simplify its possible reconstruction as a standard drop and to require but a single calibration according to § *o* and § *p*.

m. In regard to the shape of bearing blocks and caps, no directions are as yet given, in view of the still missing results of experiments; it is, however, recommended that a description of the exact shapes used be given, whenever reports of tests are published, or when certificates of test results are issued.

n. Drops up to 6 m. (19.68 ft.) high ought to be considered more reliable than those of greater height, and it is, therefore, recommended that 6 m. (19.68 ft.) be not exceeded. For heavier tests a drop weight of 1,000 kilos (2,204.7 lbs.) ought to be used.

Drops up to 6 m. (19.68 ft.) high can be more readily erected under cover and with greater reliability; they are less liable to alteration of detail than those that are larger.

o. The work of impact is determined by the effective weight and the distance through which it falls. The total mass of the weight dropped is to be so rectified that the effective weight is a convenient number; *i. e.*, 500 kilos (1,101.25 lbs.).

Comparable results are only obtainable when the loss due to friction is considered or eliminated.

p. The following methods can be adopted to determine the effective weight of the drop:

α. A spring balance of proper force is attached between the weight and the lifting rope, and the indication read *while* the weight is slowly *descending;* thus the dead weight *less* the friction is obtained. While raising the weight, the dead weight *plus* the friction is found.

β. The weight of the drop is determined by the effect produced by the blow due to a given drop upon a standard plug of best staybolt copper placed exactly central, and which has an exact shape and weight which are still to be determined.

q. Such standard copper plugs are also to be used to compare different drops and to standardize them.

Such tests and plugs have already been made by the Testing Laboratory at Charlottenburg, which will undoubtedly make others, in future, upon request.

r. Drops which have an absorption of work due to friction of more than 2% of that produced by shock are to be discarded.

For *governing drop tests* only the most perfect drops are to be used, while on the other hand all those poorly constructed or entertained are to be avoided.

For the *method* of *testing*, the following principles are laid down:

s. The standard drop is intended principally to test *whole* or *finished pieces*, such as rails, axles, tires, springs, etc., etc.

Tests of specially prepared pieces are of the greatest value, but instructions for the construction of a special small drop or the establishment of rules for the execution of such tests are not considered advisable, inasmuch as such tests are primarily of a scientific character.

t. The guides are always to be in a truly vertical position, and this as well as correct position of the weight in the guides is always to be ascertained. The point of impact vertically below the centre of gravity of the weight is to be carefully marked on the anvil and is to be verified before each test, in order to place that point of the test piece to be struck exactly below the centre of gravity of the weight; and the test piece must be so placed that no tilting or displacement is produced by the impact.

u. Inasmuch as the work done in a drop within very wide limits is dependent only upon the product of effective weight by the height of fall, but not upon the magnitude of either of the factors, it is recommended to adopt the metre-ton as the measure of work, and for the work to be done only such quantities which are multiples of five hundred; the divisions on the scale must then be divided into half metres instead of metres.

v. It is recommended to adopt sliding scales in order to be able to place the zero point always on a level with the top of the test piece.

w. At present it is considered sufficient if deflections of test pieces 1.0 m. (3.28 feet) to 1.5 m. (4.92 feet), between bearings be determined to 1 mm. (0.0394 inches).

x. With the view of making results of tests comparable, it is recommended when publishing results of tests to annotate all

details of procedure during the test (*i. e.*, the order of blows, whether continuous or intermittent, whether the test piece was reversed or not), as well as all details of behavior of test pieces.

y. The Standing Committee *shall examine new propositions for drops and drop tests, and particularly gather and collate published experiments and researches, with the view of establishing a standard method of test. The Vienna Conference has directed that the designs presented by Engineer Schmitz be further studied and reported upon.*

II. TESTING OF WROUGHT IRON* AND STEEL.

A. Rails.

1. Rails, for reasons of safety of traffic, and in accordance with the decisions under I. No. 8, must be subjected to the *drop test*, by means of proper technical arrangements (standard drop, see I. No. 9).

2. When further knowledge of the quality of the material is desirable, the *tension test* is to be made.

3. Finally, rails should be subjected to *bending test* (by static load) and in two ways: one to determine the "yield point" by permanent set; the other to determine the amount of *permanent deflection* under excessive loads beyond the elastic limit.

That tension tests *alone* were not sufficient for testing rails was the universal opinion of the Munich Conference. The contradictions of the results of such tests as emphasized by *Tetmajer*, and as demonstrated on Finnish, Swiss, and French railways, plainly gave evidence to the contrary. If, on the one hand, these contradictions are the result of the fact that the rails are subjected to shock, and on the other hand, the tension test merely indicates the character of a small part of the rail section, it certainly seems advisable to lay more stress upon the drop and bending tests, but emphasizing the application of *proper* apparatus, for the former, especially the standard drop. As these latter, however, do not give as much information about the character of the material as tension tests, particularly when accompanied by chemical analysis, they must be still resorted to, as long as such information is desirable. With our comparatively limited experience thus far gained in that respect, this will no doubt have to be done for some time to come. Comparative results of both kinds of tests of the same material, such as are now being executed at Berlin, will have to decide which procedure is to be preferred, or whether both are to be used hereafter conjointly.

4. For testing rails by tension, the test piece is to be cut in *rectangular form* from the extreme elements.

* This name is adopted in contradistinction to cast iron, and is intended to include weldable iron and low steels.

As a concomitant reason for the unreliability of tension tests of rails, is to be mentioned the fact that the test pieces heretofore were turned specimens taken from the middle of the head, and did not at all test the parts most subject to wear and tear, such as the head and foot ; and furthermore, that the injurious bubbles of silicious gases in metal, poured very hot, are always found near the surface of the ingots. On the other hand, it is to be remarked, that pure steel solidified by the admixture of manganese contains a porous central zone in the ingots, which may affect the tension test, but in no way deteriorates the rail, and may thus be the cause of erroneous conclusions.*

5. The formulation of proper methods of determining wear of rails and tires is synonymous with the research of proper methods of determining wear in general. It has been determined that

(*a*) *One* test is not sufficient to determine abrasion ; and

(*b*) The test must be made under conditions which most closely resemble those to which the material is subjected when in actual use. The difficulty of this problem has caused its further investigation to be dropped.

6. The investigations relative to the effect of different *kinds of tires* upon the *wear* of rails must be classified as a special field of operation for railway administrations.

B. Axles.

1. Axles are to be subjected to the *drop test* at the middle as well as the ends.

2. *Tension tests* of the same are to be resorted to when additional knowledge of the material is desirable.

3. Axles need not be subjected to the *bending test.*

C. Tires.

1. Tires are to be subjected the same as rails and axles to the *drop tests.*

2. *Tension tests* are to be resorted to where additional information is desired as above.

3. *Hammer test* is *not* necessary.

D. Multiple or piece tests.

1. *It is desirable to obtain as much information as possible about multiple tests (tests of every piece of a lot of material) in order to be able to formulate a standard method of procedure.*

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* See pp. 42–53, Part III., of "Mittheilungen."

2. *In the construction of drops and testing machines the possibility of making multiple tests is to be kept in view.*

3. *Not only axles are to be kept in view, but also all building and structural pieces of iron and steel.*

The multiple test, *i. e.*, a method which is as rapid a test-process as possible, such as a blow given to each piece of a delivery to judge of the quality, without, however, doing any injury, is certainly as appropriate to assure a higher degree of certainty, as the one now generally in vogue of testing merely a percentage of the delivery or a number of pieces of a load. It has long ago been adopted for springs, chains, pipes, boilers, cylinders, etc.; as in Austria, where the multiple test has been frequently applied to axles with very good results. On the other hand, the fact must not be lost sight of, that its application is combined with considerable difficulty for buyers as well as manufacturers, which might, however, be overcome by the introduction of a proper method of testing. In Witkowitz alone have such tests of car axles been made which have caused their abolition. It is, however, highly desirable to collect further data on the same.

E. Wrought iron for bridge construction.

1. Wrought iron for bridge construction shall be subjected to the *tension tests*, as well as

2. The *bending test*, and this by a static load applied by mechanical means, the material to be tested hot as well as cold, and bent around a stud uniformly of 25 mm. (0.985 inch) diameter.

The conditions to be fulfilled by this mechanical device are given below, (see *N*, p. 1285).

3. The flattening or spreading as well as fracture test need not be resorted to, as the two tests above indicated sufficiently characterize the material.

F. Low steels for bridge construction.

1. Low steels as well as wrought iron are to be subjected to the *tension test*, as well as

2. The *bending test*, by a static load applied slowly by mechanical means, the material being tested hot and cold, and bent around a stud uniformly 25 mm. diameter (1 inch).

G. Wrought Iron for Boiler Work.

1. For the three shapes used in boilers made of wrought iron the following tests are to be made:

a. For *Plates.*

1. Tension test.
2. Bending test.
3. Forging and punching tests.

b. For *Angle Irons.*

1. Tension test.
2. Bending test.
3. Forging and punching tests.

c. For *Rivet Rods.*

1. Tension test.
2. Bending and forging tests.

2. Angle irons need not be tested for their welding qualities, but this is desirable.

3. Red shortness, which could be established by the welding test, is determined by the bending test with hot specimens.

H. Low steels for boiler construction.

Low steel (Bessemer, Martin and Thomas materials), when taking the place of wrought iron in boiler construction (stationary locomotive and marine boilers, etc.), shall, in order to conform to standard methods, be tested as follows:

1. By *tension test.*

2. By the *bending test, cold* and at a *red heat.* The edges are to be trimmed, and for plates above 6 mm. (.236 inch) thickness the specimens are to be bent to a given angle, around a stud uniformly 20 mm. (9.85 inch) diameter, by the use of a slow-operating mechanical device.

By these tests the behavior of the material when actually worked, and its suitability for the work, are determined. The stud uniformly 25 m. per .985 inch diameter is convenient, and harmonizes with most of the present specifications.

3. By the *quenching test.* The specimens with edges trimmed are to be uniformly heated throughout to a dull cherry red (about 550–650° *C.* [1022–1202° F.]), and quenched in water of a temperature of 25° (*C.* 77° *F.*), and then tested as stated under 2.

Experience has taught that the softness of low steels for boiler work is to be such that the hardness produced by quenching is so slight that it shall in no way prevent the material from being worked readily. Material having a tenacity of from 38–42 kg. per sq. mm. (50,000–60,000 lbs. per square inch), with 20% elongation, is generally suitable; but still it is safer to determine this point by the above quenching test.

4. By the *forging test* (spreading test), which is always to be made at a red heat.

The punching test need not be made, as punching of low steel

plates is to be avoided, on account of the peculiar incipient fractures produced.

5. Addendum : Those establishments which habitually use low steels are recommended to test the material as well for its *welding* properties.

The principal reasons against the general introduction of the welding test, are the difficulty of its execution, its dependence upon the degree of skill and experience of the workman, and also the circumstance that the material is weldable with some difficulty, but not with such certainty that a riveted joint is not, perhaps, preferable. The rolled and corrugated Fox boiler flues are, however, welded, as well as the ordinary flues, and low steel gas conduits, but they are all individually tested.

Weldable low steel, moreover, does not harden when quenched, or only very slightly, and is much less affected by temperature, but this is determined by the quenching test.

Tests of low steel plates after being annealed can be omitted ; the following reasons make it appear not advisable : Such plates are not always annealed before use, principally on account of the cost. Only plates of small diameter are rolled or curved while hot : hand flanging is done by heating the plates locally little by little ; corrugated or pitted heads are no longer annealed, as are flat heads to prevent distortion.

The presence of internal strain cannot be decided by this test.

It is difficult to determine the temperature at which the material is annealed, and this, as well as time, exerts considerable influence. Determinations of temperature would make the tests very laborious. And, after all, material is always to be tested in the condition in which it is delivered.

In favor of testing the material after annealing, may be mentioned that comparable results of tests of plate can only be obtained after eliminating internal strains by annealing, *i. e.*, its natural condition ; also, that the same material when rolled into plates of various thicknesses gives varying results ; and, finally, that comparisons of tests of the material as from the rolls and annealed discover defects, which are produced by careless manipulation during fabrication.

6. *Location* and *method* of obtaining test pieces from *Boiler Plates*, and especially from such as have been in service.

(1) Flat Plates, before fabrication into boilers.

Test pieces for longitudinal and transverse strength are to be cut from the edges in trimmed plates, and from the trimmings on the sides and crop-ends, in the case of untrimmed plates.

In the latter case test pieces are to be cut at least $1\frac{3}{16}$ inch (30 mm.) distant from the extreme edges of the plates.

Strips may be sheared or sawed off.

Test pieces from bridge-material when cut off by shears are to be straightened cold, either under a press, or by means of wood, copper, or lead hammers, and must be planed off at least $\frac{3}{16}$ inch (5 mm.) at each edge before testing, in order to remove the

effect of shearing; test pieces for boiler plate when sheared must be straightened and planed as above.

Reheating or annealing is to be undertaken only when specially instructed to do so.

(2) PLATES WHICH HAD BEEN WHOLLY OR PARTLY FINISHED AND USED IN BOILERS.

a. To determine by test what were the properties of the material *before* fabrication.

In this case test pieces are to be selected from a part of the plate which has not been changed in thickness by the working, and which, if possible, had not been curved.

In case only a curved plate can be used for testing, then the strips must be cut out by drilling holes, chipping, or the circular saw. In the case of straight plates, test strips may be cut out by shearing, and they are then to be prepared as above.

Curved strips for testing are to be straightened under the press, or by means of wood, copper, or lead hammers, or by means of iron hammers provided the coupon is sandwiched between slabs of hard wood, and then carefully treated. After this the strips are to be prepared as above.

b. To determine the mechanical properties of plates *after* they have been worked upon.

No specific instructions can be established as to location of test pieces or making tests in this case; the previous rules should, however, be adhered to or followed as closely as possible.

J. Wire.

Wire is to be subjected to the following tests:

1. *Tension test.*

2. *Winding test*, and this by mechanisms which exclude arbitrariness.

3. Bending test, by *repeatedly bending* the wire *forward* and *back*, by the use of mechanism, bending around a stud uniformly 5 mm. diameter.

Establishing a stud of definite diameter precludes the abominable habit of clamping the wire in a vice with square jaws, over which the wire is bent forward and backward.

The Standing Committee is directed to examine and report at the next conference upon a new wire testing apparatus in use in the United States and described by G. C. Henning of New York.

K. Wire-ropes.

Wire-ropes are to be tested by :

1. *Tension test.*
2. Test by *impact* and *concussion* longitudinally.

The bending test would only then be valuable when applied to determine durability, but that is, practically, very difficult and unnecessary, as each wire in the rope has already been tested for reverse bending.

L. Measurements during the Tension Test.

1. During tension tests the following observations are to be made :

a. Tenacity.

b. Contraction at the point of rupture.

c. Elongation after rupture (compare under *M*, No. 1).

d. Limit of elasticity or limit of proportional extensions.

2. It is recommended for the determination of the *diagram of work done* (resilience) to make as many individual or single observations, in case a special apparatus is not already used for recording this diagram.

3. When taking such diagrams it is of essential value to indicate the *time* (rate) of taking them.

4. When taking diagrams the following five points are to be determined with the greatest possible precision :

a. Elastic limit (limit of proportional extensions).

b. Yield-point.

c. Instant or point of contraction.

d. Maximum load (drop of beam).

e. Rupture.

5. The contents of the diagram of work of resistance are to be considered up to the point of rupture.

Only that part of the work done by the rod up to the point of contraction need be determined ; after that instant the part contracting is the one mainly doing work, and the latter is of no great value in most structural materials ; as the determination of the area of the diagram of work up to the point of rupture can produce no great error in the whole value, it may as yet be retained, as the determination of the instant of maximum load is very difficult. Furthermore, the separate consideration of that part of the diagram obtained after contraction commences is desirable, because possibly there may exist some relation between extension of test piece after that point is reached and the work done to produce it.

M. Shape of Test Piece for Tension Test.

1. *Round rods* are to be prepared in four types, with diameters of 10, 15, 20, and 25 mm. (.394, .591, .799, .985 inch), according to requirements or possibility; the cylindrical part to extend 0.4 inch (10 mm.) beyond each of the gauge marks; distance between gauge marks is to be that on which measurements of elongation are to be made.

The gauge length (l), in order to insure that per cent. of elongation be independent of shape and dimensions of cross-section, must be proportional to the square root of the cross-sectional area (f), and should be $l = 11.3\sqrt{f}$* in case the test piece is of $\frac{3}{4}$ inch (20 mm.) diameter, and 8 inches (200 mm.) gauge length, or $8\frac{3}{4}$ inches (220 mm.) turned length, which has already become the international standard.

Elongation is to be measured on two opposite sides of the test

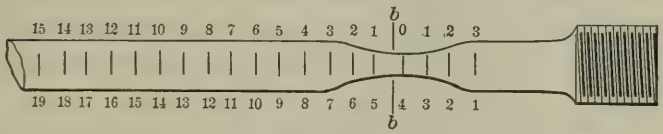

FIG. 456.

piece, by taking one-half of the sum of the measurements from the gauge marks to the point of fracture.

Should fracture occur outside of the middle third of the gauge length, then the test is to be discarded as worthless, or else the following method is to be pursued in order to obtain the correct elongation.

For this it is assumed that the gauge length has been divided into a given number of equal parts, and the elongation after rupture (see *L*, No. 1, *c*) is to be determined as follows: Supposing the rupture to occur as shown in Fig. 456, between divisions 4 and 5. Measurements can be made to the left from 1 to 5, or 1 to 10, adding 0-*b* and 1-*b* to each (using figures inscribed above the rod) accordingly as 10 or 20 equal parts were marked

* In the United States this formula would be $l = 12.0\sqrt{f}$ if based on a length of 8 inches and a diameter of $\frac{3}{4}$ inch. If the standard diameter be changed to 0.799 inch, the length remaining the same, then the European formula for proportions will be the same in the United States.

on the gauge length. Toward the right, however, only 0–3 can be determined; and assuming that the elongation beyond the section contracted is identical, the value taken from 3–5 or from 3–10, accordingly as 10 or 20 parts are assumed as standard length, is to be added to obtain the total elongation of 10 or 20 parts. In this way the measurements are so taken that the elongation is nearly the same as though the rupture had taken place in the centre of the specimen.

These divisions (marking) and measurements of elongation after rupture are always to be made on two opposite sides of the test piece.

2. The gauge and standard length of *flat rods* is dependent upon the dimensions of section and is the same as for round rods, hence $l = 11.3\sqrt{f}$, this length meaning the same thing in both cases. The divisions or marking, as well as the determination of elongation, are always to be made on both sides of test pieces.

It is recommended that elongation in the case of flats be measured on the two edges and also on one wide side, and that the latter and the mean of the former be noted separately in each case.

3. In such cases where width and thickness of test pieces of *rectangular section* can be chosen at will, the width shall be 30 mm. (1.18 inch) and the thickness 10 mm. (.394 inch), but in all cases the section of 30×10 mm. is to be considered as the standard.

In place of the width of 50 mm. (1.97 inch), formerly customary, one of 30 mm. (1.18 inch), is to be substituted, with reference to the smaller testing machines, largely used in works, which generally can exert a force of but 50 tonnes (55.12 tons).

4. Where the thickness is fixed in plates, the width of test piece is to be 30 mm. (1.18 inch) up to a thickness of 24 mm. (.945 inch), and from 25 mm. (.985 inch) upward the thickness of plate is to be chosen as width of test piece, and this made 10 mm. (.394 inch) thick.

In order to retain the surface produced by the rolls in this case, the shoulders are to be cut out of the *width* of the plate.

Exceptionally, where smaller testing machines only are available, the limits of 16 mm. and 17 mm. (.630 and .670 inch) may be taken instead of 24 mm. and 25 mm. (.945 and .985 inch).

5. Test pieces from flat bars, angles, tees, and I beams, as well as channels, etc., etc., are to be cut *lengthwise*, in the shape of *rectangular bars*, and not more than 1.18 inch (30 mm.) width of section. When the thickness of bars, angles, channels, etc., etc., exceeds this, then specimens are to be cut *lengthwise*, so that the whole section is represented by the test pieces, by taking two or more lying parallel and side by side in the original bar, or as shown by Fig. 457 which represents a channel bar.

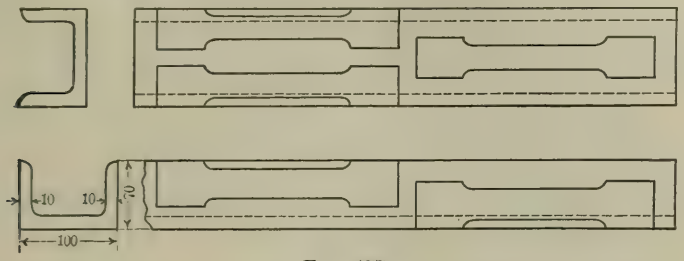

FIG. 457.

6. The surface in contact with the rolls must invariably remain on the test pieces.

N. Bending Tests.

A slowly working *mechanism* by which bending tests are to be made (see ante *E*, 2) must fulfil the following conditions:

1. Machines applying the power centrally between two supports, as well as such which clamp the test piece at one end and apply the power laterally, may be used. They must be simple and work rapidly. The free part of the test piece must be readily visible. Flexure must take place steadily. When bending about a pin, its diameter should be as small as possible.

2. Test pieces shall have an oblong section, width to thickness to be as 3 : 1; the edges to be slightly rounded off; rivet rods and squares are to be tested in the condition in which they come from the rolls.

3. Hot bending tests (at copper color) are to be made as rapidly as possible. The rate of bending in the case of tests at ordinary temperatures is immaterial.

4. For determination of deformation, measurement of the angle to which the piece has been bent is not alone sufficient; it is also necessary to measure the radius of curvature on the

convex side. This can be done directly by templets or indirectly by measuring the extension on the tension side.

The Standing Committee shall determine the most appropriate and simple method of measurement. Bending tests with nicked test pieces are also to be considered in its further work. The Standing Committee is to devise ways and means by which the frequently abnormal qualities of low-steels, which are manifested by sudden fracture—although test pieces cut adjacent to such fractures show normal qualities—can be determined. All proper parties are to be addressed with the request to submit such abnormal cases—should any occur—to the Standing Committee for purpose of searching study, tests and chemical analyses.

III. TESTS OF CAST IRON.

1. *Test pieces* are to be in the shape of prismatic bars 43 inches long (110 cm. standard length), and have a section of 1.18 inch (3.0 cm.) square.

They should have an addition on one end, one inch square, from which one inch cubes for compression tests can be cut when desired.

Larger sectional area would, however, be desirable for bending tests as well as for the facility of procuring specimens for tension tests, but in order to make them comparable with the fundamental experiments by Wachler, the above dimensions were retained.

2. These test pieces are to be cast in a position slightly inclined, rising from one end of the bar to the other. The inclination of the flask is to be one in ten.

Wachler's test bars were cast on end (but it is not stated whether poured from below or above), but experience has taught that with some kinds of iron the metal chills too readily, when bottom poured, and experience in pouring from above is still lacking. The method of casting is, moreover, dependent upon the quality of the cast iron, upon the skill of the moulder and caster, etc.; therefore the above final injunction.

3. The head of pressure under which the test bars are to be cast is to be equal to a gate eight inches high above the opening.

4. Dry sand moulds are to be used.

5. During the test the points to be determined are as follows:

a. Resistance to flexure and work done during bending, up to the point of rupture, using three test pieces.

b. The *tenacity* as determined from turned test pieces 20 mm. diameter and 200 mm. (.785 inch × 7.85 inch) standard length, cut from the two ends of the test piece broken by flexure, and two of these out of each of the three first tested.

c. Compression, determined from cubes 3 c.m. (1.18 inch) on each side, cut from the pieces obtained by *a*, and two such out of each bar. Pressure to be applied in the direction of the axis of the original bar.

6. The bars for bending, and the cubes for compression test are to be tested as taken from the sand, with the scale on.

7. Special cast pieces, such as bearing plates for bridges, water pipes, etc., etc., are to be submitted to special test in accordance with the uses to which the pieces are to be put.

IV. TESTS OF COPPER, BRONZE, AND OTHER METALS.

1. Copper.

To determine the quality of copper in the shape of plates, sheets, bar, and wire, the following tests are considered necessary:

A. Copper in Plates, Sheets, and Bars.

1. Tension test.
2. Bending test when cold.
3. Bending test when hot.

B. Copper-wire.

1. Tension test.
2. Bending test.
3. Twisting test.

a. Condition of Material.

Tests are made with the material in its commercial condition, or when in shape as under *A*, and so requested, after softening. In order to determine the quality of the material in its natural condition, the test pieces must first be softened (annealed). To do this it becomes necessary to heat the roughed-out test pieces to a temperature of 1112–1292° Fahr. (600–700° C.), but not above, in an annealing furnace, then allowed to cool in air until black, and then in water of a temperature of 59° Fahr. (15° C.).

b. Test Pieces.

Test pieces must be cut from the material when cold, by means of a saw, the file, or any machine tool, care being taken to avoid necessity of straightening afterward. Straightening must in all cases be done with the greatest care, by means of wood or copper hammers. In case tests are to be made on soft material, then the partly finished test pieces may be heated for purposes of straightening. However, in this case they must be annealed once more before testing.

c. Shape and Preparation of Test Pieces.

The gauge length, l, of test pieces of cross-sectional area, f, is to be obtained exactly as in the case of wrought iron and steel (see p. 1283 under *II. M*, 1), by the formula $l = 11.3\sqrt{f}$.

As the work on test pieces of copper has the greatest influence on the results, it is absolutely necessary to exercise the utmost care in their preparation, and particular attention must be paid to fine finishing cuts, and the cutting tool must never be removed between gauge marks for any reason, but the cuts run out to the shoulders. The finishing cuts must be very light. The strips are to be draw-filed, and then polished with fine emery-paper. Pieces for cold and warm bending tests are to have their corners filed off round at the point where bent.

It is also advisable to file the corners rounding to $\frac{1}{32}$ inch radius, on strips for tension tests.

d. Method of Test.

Tension test and measurement of elongation are to be made the same as in wrought iron and steel.

The cold bending test of plates, sheets, bars, and wire is to be made about a pin of a diameter equal the thickness of material; the temperature when testing must never be less than 50° Fahr. (10° C.). All shapes except wire, after having been bent 180°, are then to be pressed flat until closed down. Wire is tested in accordance with directions for iron and steel wire, as above.

Hot bending test is to be made on strips heated to a cherry-red in an annealing furnace, and they are to be bent until cracks appear or until closed down closely. The *twisting test* is to be made the same as in the case of iron and steel wire.

2. Metals and Alloys.

These metals, used in machinery, bridges, railways, and ships, it is considered necessary to test by:

1. Tension test.
2. Compression test.
3. Bending test.
4. Bending test, cold and hot.

According to the properties of the materials to be tested, the methods are to approach those for iron and steel, or those for copper. In the former case, tests 1–3 and in the latter, 1, 2, and 4 are recommended.

Proper appreciation of the crushing test, and compilation of directions for making same, and not alone for testing copper, bronze, and other alloys, but also in the case of iron and steel, are intrusted to the Standing Committee.

V. TESTS OF WOOD.

1. Necessary parts of a technical opinion of woods are (as far as possible): Information of location of forest; the locality in which the tree grew from which the specimens were obtained, whether crowded in a dense forest or in an open spot; from which part of the tree the wood was cut; finally, statement of age and time of year when felled.

2. To form a technical opinion on woods at least three samples are necessary, on account of the great difference existing between single individuals and even pieces.

3. Of each test piece a description of external appearance is to be given as follows:

A. Of the *longitudinal cut*, or better still, surface as produced by splitting; making note of
  a. Straight position of fibres or otherwise.
  b. The presence or absence of knots or ingrown limb buts.

B. Appearance of *cross section;* giving—
  a. When examining leaf trees and all members belonging to the pine family—
    α. The average radial width of rings in mm.;
    β. The increase or decrease or the change of width of rings on one-half diameter;
    γ. Circular or eccentric arrangement of rings; and
    δ. In all pines the average proportion of spring and autumn growth of all the rings.

4. The specific weight of each test piece is to be determined in the condition of moisture in which it happens to be tested, as well as after thorough drying in a temperature of from 101° to 105° C. (214°–221° Fahr.). The difference in moisture in these two conditions is also to be determined.

5. *Compression* and *transverse tests* are to be the means of determining the solidity or strength and resilience of woods.

a. For the compression test prismatic blocks are to be used, having a section of 10 cm. by 10 cm. (3.94 × 3.94 inches), and a length of 15 cm. (5.91 inches), with exactly concentric position and parallel bearing surfaces.

b. Transverse strength is to be determined from prismatic pieces 10 cm. by 10 cm. (3.94 × 3.94 inches), in cross sections, 160 cm. (63 0 inches) long, with 150 cm. (59.1 inches) c. to c. of bearings. The point of application of the force is to be protected against injury by a rider of 2 cm. (.788 inch) thickness, and 20 cm. (7.88 inches) length, or other satisfactory means. Flexure is to be carried up to rupture. Rupture of single bundles of fibres or splitting in or separation of layers is not to be considered as rupture.

c. The fibre strains at the time of rupture are to be determined from the usual formulæ for flexure, under the assumption that it is applicable up to the instant of rupture.

d. The determination of the resistance or quality of the wood is effected by means of the *work done* during *flexure* by the test piece of above dimensions, represented by the diagram of resistance up to the instant of maximum load.

6. In order to determine the resistance of whole trunks the separate sections of which show differences, the compression and bending tests as above are to be executed, and upon at least two pieces cut from the centre and two selected so that the extreme edges coincide with the surface of the trunk; from these the correct mean of the whole trunk is obtained.

7. The relative position of rings and direction of application of force in these tests is to be represented by a diagram. Sapwood is to be strained in the direction of the radius of the rings, with the heart on the concave and surface on convex side of curve produced by flexure.

VI. TESTING OF MATERIALS FOR SHIP BUILDING.

1. Materials used in ship construction, such as **wrought iron** in the shape of plates, bars, angles, shape and rivet iron, are to be tested by:

a. *Tension test.*

b. *Bending test* while *cold.*

c. *Bending test* while at a *red heat*, or forge test.

2. Such as **low steels** and **cast steels**, in the shape of plates, bars, angles, shape and rivet iron, are to be tested by:

a. *Tension test.*

b. *Bending test* while *cold.*

c. *Bending test* while at a *red heat*, or forge test.

d. *Hardening* or *temper test* by flexure.

e. Parties who habitually use low steels for ship building are recommended to examine the material furnished, for its welding properties.

The tests of resistance of the materials are to be made with standard test pieces, in the condition in which the material is furnished. The specimens for bending tests are to be obtained precisely as prescribed for boiler plates (see above under II., *G*, *H*, and *N*).

The hardening and bending tests are to be made precisely as above, with the difference that the bars are to be bent by a slowly operating mechanical device, using, however, studs which will produce bending of the inner surface to a *radius proportional* to the *thickness of plate.*

VII. TESTS OF STONE.

A. Stone in General.

Stone is to be examined for its *resistance* to *boring* or *quarrying*, in accordance with uniform methods, in the following manner:

1. *Trial methods.*

The trials for the determination of resistance to boring stone are to be made by—

a. A jumper or drill; or

b. By rotary boring machines.

For testing by jumper or drill is to be recommended an apparatus such as was used by mine surveyor Hausse, of Zankerrode, in his tests of the resistance of stone to boring, and which was

described in the "Deutsche Berg und Hüttenmännische Zeitung," 1882, Nos. 33 and 34. By such an one or a similar one, or else by a boring machine, the work done in metre-kilograms required to bore a hole of given dimensions is determined.

2. *Determination of the proper preliminary work before the execution of the actual tests of strength.*

Because the least work done upon a stone of given quality with a given size of hole is largely dependent upon—

a. The moment of drop of a jumper, or the force required to advance the borer, as also its velocity of rotation; and

b. The shape and cutting angle of drill, or of the teeth of the boring tool; and

c. The number of blows for one revolution of drill, when drilling by percussion; it is recommended to determine by preliminary trials the most favorable combination of conditions under which the actual tests are to be carried out. As a starting point it may be stated, that for a drilled hole 25 mm. diameter, the most favorable moment of drop lies between 6 and 9 metre-kilograms, and that the pressure in boring machines varies from 30 to 130 atmospheres; also, that in percussion drills, the most favorable angle of cutting edge lies between 70° and 110° *C.*, with from 12 to 60 blows per one revolution of drill; and, finally, that with existing boring machine the most favorable diameter of bore varies from 40 mm. to 80 mm. (1.576—3.152 inches).

3. *Special standard procedure.*

After the most favorable method of working the particular variety of stone has been determined by the preliminary investigations, a diameter of hole of 25 mm. (.985 inch) shall be adopted as the invariable standard when using a *percussion drill* (jumper), this being about the approximate hole drilled by a single (one man) drill. However, in order to determine the effect on the work done, of the size of hole drilled, holes of larger diameter are to be drilled, and for this 35, 45, and 65 mm. diameter (1.379, 1.773 and 2.561 inches), corresponding to the average holes produced by two and three men or power drills, are recommended. When these larger diameters of holes are investigated by drilling, then the most favorable moment of drop (moment of impact) is to be determined, on the basis of the law of proportional resistances, starting with the most favorable moment of impact for drilling a hole 25 mm. (.985 inch) diameter, which has been determined empirically beforehand.

For *boring experiments* no fixed diameter can be prescribed, as this is dependent upon the existing boring machine at hand, but it is recommended in such cases to adhere as closely as practicable to the diameters of drill holes of 45 and 65 mm. (1.773 × 2.561 inches).

4. *Additional tests.*

For the purpose of information it appears desirable that stone examined for resistance to boring be also investigated for compressive strength, elasticity and resistance to shearing.

5. *Test report of boring test.*

For the reports of results obtained the following blank form is to be filled up as indicated:

STANDARD REPORT BLANK FOR BORING TEST.

1.	Description of stone in its geological and mineralogical relations.
2.	Miner's classification (hard, very hard, or extremely hard).
3.	Texture (*i. e.*, coarse grained, fine grained, parallel, normal to or inclined to axis of drill hole).
4.	Specific gravity of the stone.
5.	Diameter of hole drilled.
6.	Diameter of hole and core when boring.
7.	Straight or curve edged drills.
8.	Angle of edge of drills.
9.	Number of blows per revolution of drill.
10.	Effective weight of drill.
11.	Mean effective drop of drill.
12.	Number of blows required to drill the depth of hole.
13.	Number and form of teeth of borer.
14.	Statement of pressure on and velocity of borer while boring.
15.	Actual or total depth of bore hole.
16.	Calculated or indicated work done during boring stated in metre-kilograms per cm. of hole bored. (When using a hollow borer the annulus of stone cut away is alone to be considered.)

B. Building Stones.

a. Natural Building Stone.

1. In addition to the petrographic and geologic description of the stone, its fracture and location of stratum from which the sample is obtained are to be clearly stated. Also the time of quarrying, as well as the deposit. When the quarry is very wet the sample is to be obtained in the dry season. Inasmuch as it is often difficult for the investigator to examine the correctness of mineralogical nomenclature given by the client, it is to be

recommended to desist expressly from this examination unless the contrary is requested, and to so record it in the test report; on the other hand, it is desirable to rectify palpable incorrectness of nomenclature of the stone, by a communication relative thereto to the client.

Similarly in a given case, the verification of statements relative to locality and stratum of quarry from which the sample has been obtained, may be also neglected, and the test report can be made to read about as follows: Stated to be obtained from the ——— quarries, found in the ——— bed or stratum.

2. It is to be recommended that the investigator make particular inquiries about the intended utilization of the stone by the client (whether as building or cutting stone, for sidewalks, for pavements, or for ballast or macadam), before commencing the tests, and then to execute them *in accordance* with *these*, and not the accidental wording of the order.

3. Stone, which is to be used as cut stone for sub- or superstructure, is to be tested for *resistance* to *compression*, and in the shape of cubes, with planed bearing surfaces lying between pressure plates without the interposition of other substances; one of these plates must have free motion in all directions. The compressive strength is to be determined normal or parallel to the bed of the stone, or both, according to the utilization of the stone, and the tests in each direction are to be made in triplicate.

Test pieces should be selected as large as possible, according to the relative strength and the capacity of the testing machine, but for weaker stone a cube measuring 10 cm. (3.94 inches) on each side is sufficient.

4. In addition to this, rectangular pieces are to be tested, from which the compression due to increasing loads is to be determined and the diagram of work constructed. Similarly tension and bending tests are to be made and plotted.

5. Test pieces shall be tested in a perfectly dry state, obtained by submitting them to a temperature of 30 C. (86° F.) until there is no further diminution of weight.

6. The specific gravity (weight of the unit of volume) of stone is invariably to be determined, and always after drying at 30° C. (86° F.).

7. The examination of *resistance to frost* is to be determined from samples of uniform size, inasmuch as the absorption of

water and action of frost are directly proportional to the surface exposed, and with a view to the same test of cements this block is to be a cube of 7 cm. (2.76 inches) length of edges. Smaller dimensions are only permissible with very hard stones ; although the frost-resisting qualities in these are rarely in doubt.

8. The *frost test* consists of :

a. The determination of the *compressive strength* of *saturated* stones, and its comparison with that of dried pieces.

b. The determination of *compressive strength* of the dried stone after having been frozen and thawed out twenty-five times, and its comparison with that of dried pieces not so treated.

c. The determination of the loss of weight of the stone after the twenty-fifth frost and thaw ; special attention must be had to the loss of those particles which are detached by the *mechanical* action, and also those lost by solution in a definite quantity of water.

d. The examination of the frozen stone by use of a magnifying glass, to determine particularly whether fissures or scaling occurred.

9. For the frost test are to be used :

Six pieces for compression tests in dry condition, three normal and three parallel to the bed of the stone, provided these tests have not already been made (as under No. 3 above), in which it is permissible, on account of the law of proportions, to use test blocks larger than 7 cm. (2.76 inch) cube.

Six test pieces in saturated condition, not frozen, however; three tested normal to, and three parallel to, bed.

Six test pieces for tests when frozen, three of which are to be tested normal to, and three parallel to, bed of stone.

10. When making the freezing test the following details are to be observed :

a. During the absorption of water, the cubes are at first to be immersed by 2 cm. (.77 inch) deep, and are to be lowered little by little until finally submerged.

b. For immersion distilled water is to be used at a temperature of from 15° C. (59° F.) to 20° C. (68° F.).

c. The saturated blocks are to be subjected to temperatures of from − 10° to − 15° C. (14° to 5° F.).

d. The blocks are to be subjected to the influence of such cold for four hours, and they are to be thus treated when completely saturated.

e. The blocks are to be thawed out in a *given quantity* of distilled water at from 59° F. to 64° F.

11. An investigation of *weathering* qualities, stability under influences of atmospheric changes, can be neglected when the frost test has been made. However, the effects in this respect in nature are to be carefully observed, and experience previously had in the utilization of such material is to be carefully collated, with special observation of

a. The effect of the Sun, in producing cracks and rupture of stones.

b. The effect of the Air, whether producing carbonic acid gas.

c. The effect of Rain and moisture in regard to partial solution and disintegration; and, finally, the effect of

d. Temperature.

β. Artificial Building Stone.

αα. Brick.

1. When testing bricks as found in a delivery, the least burnt are always to be selected for investigation.

2. Bricks are to be tested for *resistance* to *compression* in the shape of cubical pieces, formed by the superposition of two half bricks, which are to be united by a thin layer of mortar consisting of pure Portland cement, and the pressure surfaces are also to be made smooth by covering them with a thin coating of the same material. At least six pieces are to be tested.

3. The *specific gravity* of bricks is to be determined.

4. In order to control the uniformity of the material the *porosity* of the bricks is to be determined; for this purpose they are to be thoroughly dried and then submerged in water until saturated. Ten pieces are to be thoroughly dried upon an iron plate and weighed; then these bricks are to be immersed in water for twenty-four hours, in such a way that the water level stands at half the thickness; after this they are to be submerged for another twenty-four hours, then to be dried superficially and again weighed; thus the average quantity of water absorbed is determined. The porosity is always to be calculated by volume, though the per cent. of water absorbed is always to be stated in addition.

5. *Resistance* against *frost* is to be determined as follows:

a. Five of the bricks previously saturated by water are to be tested by compression.

b. The other five are put into a refrigerator which can produce a temperature of −15° C. (5° F.) at least, and kept therein for four hours; then they are removed and thawed in water of a temperature of 20° C. (68° F.). Particles which might possibly become detached are to remain in the vessels in which the stone is thawed until the end of the operation. This process of freezing is repeated twenty-five times, and the detached particles are dried and compared by weight with the original dry weight of stone. Particular attention, by using a magnifying glass, is to be given to the possible formation of cracks or laminations.

c. After freezing, the bricks are to be tested by compression. For this test they are dried, and the result obtained is to be compared with that of dry brick (see above, No. 2) not frozen.

d. Thus, freezing the bricks does not give a knowledge of the absolute frost-resisting capacity; the value of the investigation is only relative, because by it can only be determined which stone can be most easily destroyed by the action of frost.

6. To test bricks for the *presence* of *soluble salts*, five are selected, and again those which are least burnt, and then such which have not yet been moistened. Of these, again, the interior parts only are used, for which reason the bricks are split in three directions, thus producing eight pieces, of which the corners lying innermost in the brick are knocked off. These are then powdered until all passes through a sieve of 900 meshes per square centimetre (= about 5,840 per square inch), from which the dust is again separated by a sieve of 4,900 meshes * per square centimetre (31,360 per square inch), and the remaining particles on the latter are examined. Twenty-five grammes are lixiviated in 250 cubic centimetres of distilled water, boiled for about one hour, however, replenishing the quantity evaporated, filtered and washed. The quantity of soluble salts present is then determined by boiling down the solution and bringing the residue to a red heat for a short time. The quantity of soluble salts present is to be given in per cent. of the original weight of stone.

The salts obtained are to be submitted to chemical analysis.

7. Determinations of the presence of *carbonate of lime*, *pyrites*.

* These sieves are the same as those used for the examination of cements (see below, VIII. *C*, 2).

mica, and similar substances are to be made upon the unburnt clay primarily, for which purpose, too, unburnt bricks are to be furnished. These are soaked in water, and the coarse particles are separated by passing the whole material through a sieve having 400 meshes per square centimetre (about one-third mm. opening). The sand thus obtained is to be examined by the magnifying glass and hydrochloric acid to determine its mineralogical composition. When impurities such as carbonate of lime, pyrites, mica, etc., etc., are found, then pieces of brick, such, for instance, as remained from the determination of soluble salts, are to be examined in a Papin's digester for their deleterious influence. They are to be so arranged in a Papin's digester that they are not touched by the water directly, but are subjected to the action of the steam generated alone. The pressure of steam shall be one-fourth atmosphere, and the duration of test three hours. Possibly occurring disintegration is to be determined by means of the magnifying glass.

ββ. Tiles.

1. In describing tiles to be tested, both maximum and minimum dimensions are to be stated.

2. Specific gravity is to be determined with pulverized material, so fine that it will pass a sieve of 5,840 meshes per square inch, and from which all dust has been screened by a sieve of 31,360 meshes per square inch. The volumenometer is to be used for making the test.

3. The volumetric weight is to be determined by use of pieces saturated with water, by determining the displaced water; *i. e.*, by hydrostatic method. In such cases, where saturation may produce losses by abstraction of soluble salts, the volumetric weight is to be determined by the volumenometer, the test pieces having been coated with paraffine wax.

4. Absorption tests, as well as

5. Determination of salts soluble in water, and

6. Determination of injurious admixtures, such as unslaked lime,

All shall be made in a manner analogous to that prescribed in the case of natural stones, previously described (see p. 1295).

7. Tests for superficial absorption, as well as of porosity, are to be made as follows:

Pieces (chips) of sufficient size to absorb 20 to 25 cubic centi-

metres of water are selected, dried, and their edges coated with wax, and cylindric pipes of about 1.55 square inch opening are coated with wax, to be made impervious.

The following data are observed:

a. The time in which 10 cubic centimetres of water are absorbed, which is measured into the pipe by means of a pipette.

b. The time which elapses before moisture appears on the lower side of the tile after having added another 10 to 15 cubic centimetres of water.

c. The time which elapses before drops begin to form under the tile after a further addition of 10 to 15 cubic centimetres of water; or else, if the tile is porous, how much water percolates in a given time.

8. The strength of tiles is determined by fixing two ridges of Portland cement, 0.4 inch wide and 8 inches apart, across the width on one side of the tile, while a similar ridge of Portland cement is put on the opposite side and midway between them. The two strips serve as bearing points while the load is applied on the central one.

C. Paving Stone and Ballast, Natural and Artificial.

1. Information in regard to petrographic and geologic *classification*, the *origin* of the samples, etc., etc.; also:

2. Statement in regard to *utilization* of same, precisely as under the same numbers of natural stones: *B*, *α* (see p. 1293).

3. *Specific gravity* of the samples is to be determined.

4. All materials used in the construction of roads, provided they are not to be used under cover or in localities without frost, are to be tested for their *frost-resisting qualities*, by similar tests to those prescribed for natural stone above (see *B*, *α*, No. 7–10).

5. *Flagging* or stone used for *sidewalks* is tested most satisfactorily in a manner representing the mode of utilization, by determining the *wearing qualities* by a method as proposed by Professor Bauschinger and described in Part XI. of his "Mittheilungen." The uniformity of wearing qualities of burnt stone for parts more or less distant from the exterior surface is determined by repeating the trial on the same piece, and not merely testing *one*, but a *greater number* of pieces. It is, moreover, necessary to submit samples of the best, the poorest, and the medium qualities of bricks in any one delivery.

6. For the determination of the value of stone for ballast (macadam) or paving purposes, the only decisive method is to construct trial roads, on which the materials employed are sure to receive a traffic as nearly uniform in kind and weight per metre of width as possible. It is urgently desired that such trial pieces be numerously constructed by the supervisors of road construction, in a uniform manner, and special attention is hereby called to the information given by Professor Dietrich in a paper entitled "Die Baumaterialien der Steinstrassen" (materials of construction of stone roads).

7. In order to determine the value of ballast and paving stone newly introduced, in a manner more expeditious than that of the construction of trial roads, and so as not to increase the number of trial roads in proportion to the number of kinds of materials employed, it is necessary to determine a more rapid method of testing such stone. As ballast and paving materials are equally to be examined for resistance to abrasion and to frangibility, trials in a revolving drum similar to those used in France for some time past, or others as described and delineated in the above-mentioned pamphlet by Professor Dietrich, are recommended. It appears, however, that an increase in diameter to 0.3 m., and of length to 0.5 m., is necessary, in order to increase the effect of impact. The rotary velocity as well might be increased.

It is to be remarked, however, that the preparation of the trial ballast is not to be left to the client ordering the investigation, but is rather to be managed by the investigator, in order to secure greater uniformity.

It is a problem of experience to test the agreement of the results of this trial method, which ought to be preferred to the quarrying (boring) test (subject to continually varying conditions of the drill), with the results as obtained, by the trial roads themselves.

8. In addition to this drum test, ballast materials particularly are to be tested for their *resistance* to *compression*, as they are subject to crushing, and the blocks of stone for this purpose are to be cubes of from 5–7 cm.

9. Paving materials are to be tested for smoothing.

10. In ballast and paving materials, also, it seems necessary to investigate the least, partly, and most suitable grades in a delivery of any one material, as uniformity of the structure

made by them is one of the essential or primary qualities necessary.

11. Examinations of *asphalts* can only be made in an exhaustive manner by the construction of trial roads. An opinion coinciding with the results of such trial may be formed by

a. Determination of the quantity and quality of the bitumen contained therein (whether the bitumen be artificial or natural).

b. By physical and chemical determination of the residue.

c. By determination of the specific density of test pieces of the material used by a Vicat's needle of a circular sectional area of 1 sq. mm.

d. By the determination of the wear of such test pieces by abrasion or grinding trials.

e. By the determination of the resistance to frost of these test pieces.

D. Tests of Materials for Preservation of Natural and Artificial Building Stone.

1. The preservation of natural and artificial building stones shall be determined by the tension tests.

The results thus far obtained when determining the effect of materials for preservation have uniformly shown that the resistance is increased, or at least that the tendency to deterioration under the effect of repeated freezing and thawing of saturated materials is diminished. As all materials for preservation take the form of coatings and do not permeate the stones to be examined, it appears that the strength is properly indicated by tension pieces of small section.

In these the ratio of surface to volume is greater, and the effect of the preservation is more easily determined.

2. For the form of the test pieces, the German standard of 5 cm. minimum section is chosen.

All of the building stones requiring preservative treatment are soft, and can therefore be easily given the standard shape. For artificial stone the German mould can be used directly to produce the shape. The German tension apparatus is well adapted for the tests.

3. Three test pieces suffice for one series of tests. Should these, however, give decided variations, then an additional set of five pieces is to be tested.

4. The method prescribed for determining the resistance to frost as described under No. VII., B, α, and VII., B, β, for nat-

ural and artificial building stone, shall also be employed to determine the effect of preservative materials.

Also, it is recommended to determine the length or duration of the preservative effect. Practically this would be done by repeating the above tests after one and three and five years.

5. Inasmuch as the preservative effect may sometimes be due to the increased impermeability of the materials to the injurious components of the atmosphere, rather than an increased resistance, the porosity or permeability of such would be shown by the capacity of absorbing water before and after treatment, and would be expressed in per cent. (%) of weight of water absorbed by a normal or standard test piece.

6. Test pieces to determine the preservative effect must be subjected to the exact treatment prescribed for actual practice. According to the nature of the preservative material the treatment must vary, as the manner of application may materially influence the effect.

VIII. TESTS OF HYDRAULIC MORTARS.

(Bond Materials.)

A. General Remarks.

1. When using hydraulic bond material for a specific purpose, such special use and also the mixing materials at hand (such as sand, gravel, slag, etc.) must always be borne in mind when making the tests, and used in the preparation of the specimen. These tests, however, are not to take the place of the so-called standard tests.

Sewer covers and pipes are to be tested by Professor Bauschinger's method. (See Mittheilungen aus dem mech. techn. Laboratorium der techn. Hochschule in Muenchen, Heft. VII.)

2. The compressive and tensile resistance of hydraulic mortars, made in accordance with current standard methods, is not all sufficient to insure the durability of structures, as there are really several other important points to be considered as well; such as weathering qualities, brittleness, impermeability, adhesive strength, stability of volume of mortar, which are all of the greatest importance for the durability of structures.

Inasmuch as the strength of existing cement-mortars cannot be utilized, it appears superfluous from the point of view of the users of cement to still further increase it.

B. Nomenclature.

1. *Hydraulic limes* are products obtained by roasting (burning) limestones containing more or less clay (or silicic acid), and which when moistened with water become wholly or partly pulverized and slaked. According to local circumstances, these are found in trade in lumps or in a hydrated condition in the shape of a fine flour.

2. *Roman cements* are products obtained by burning clayey lime marls below the temperature of decrepitation and which do not disintegrate upon being moistened, but must be powdered by mechanical means.

3. *Portland cements* are products obtained by burning clayey marls or artificial mixtures of materials containing clay and lime, at decrepitation temperature, and are then reduced to the fineness of flour, and which contain for one part of hydraulic material at least 1.7 parts of calcareous earth. To regulate properties technically important, an admixture of two per cent. of foreign matter is admissible.

4. *Hydraulic fluxes* are natural or artificial materials, which in general do not harden of themselves, but in presence of caustic lime, and then the same as a hydraulic material; *i. e.*, puzzuolana, santorine earth, trass produced from a proper kind of volcanic tufa, blast-furnace slag, burnt clay, etc., etc.

5. *Puzzuolana cements* are products obtained by most carefully mixing hydrates of lime pulverized, with hydraulic fluxes in the condition of dust.

6. *Mixed cements* are products obtained by most carefully mixing existing cements with proper fluxes. Such bond materials are to be particularly stated as "Mixed Cements," at the same time naming the base and the flux used.

C. Testing.

1. *Weight.*

a. The determination of the specific weight of hydraulic bond materials (specific weight of the granular parts) is to be determined uniformly by the apparatus called the "Volumenometer."

b. To determine the weight of a given volume of a hydraulic

bond material, a cylindrical vessel 10 cm. high is to be used. Into this it is to be

(α) sifted, by Tetmajer's mechanism,

(β) shaken, also by Tetmajer's apparatus, and filled in by hand by use of the funnel filler and the standard liter measure.

2. *Fineness of Grain.*

The fineness is to be determined by the use of sieves of 900 and 4,900 meshes per inch for Portland cements, and of 900 and 2,500 meshes (5,732 and 31,170 per square inch; 5,732 and 15,900 per square inch) for the other hydraulic bond materials, and for each test a quantity of 1,000 gr. (2.22 lbs.) is to be used. The wires used in the above sieves shall have diameters of

0.05,	0.07,	and	0.1 mm. for sieves having
4,900,	2,500,	and	900 meshes per sq. cm.
(.00197,	.002758,		.00395 inch)
(5,732,	15,900,		31,170 meshes per sq. inch);

and it is recommended to always procure the sieves from the same makers.

3. *Set.*

a. Of all hydraulic bond materials, excepting puzzuolana (trass).

a. Conditions of set are always to be investigated at a temperature of from 59° to 65° F.

b. They are to be determined from a paste of *standard consistency.* To determine the latter the standard needle (see below) is used, combined with the "consistency meter," which is a rod of 1 cm. diameter, weighing 300 grammes (.66 lb.), and a cylindrical vessel 4 cm. high and 8 cm. diameter (1.576 × 3.152 inches) inside, made of a substance not permeable by water, and at the same time a bad heat conductor (preferably hard rubber).

To determine the standard consistency of a paste, 400 grs. of the material are stirred with a given quantity of water to make a stiff paste, which is worked by a spoon-shaped spatula for exactly three minutes for slow-setting, and one minute for quick-setting materials; this is then filled into the vessel of the consistency meter without shaking. After stroking the surface of the paste, the rod of the consistency meter is carefully inserted into the paste.

When this rod remains standing 6 mm. (.2364 inch) above the bottom of the vessel, the paste is said to have standard consistency.

c. The conditions of set are determined by the standard needle of 1 sq. mm. (0.000157 square inch) cylindrical section, and a weight of 300 grammes (0.66 lb.), and the same vessel as before.

Four hundred grammes (0.88 lb.) of the material are mixed with the quantity of water, determined as under *b*, and made into a paste, stirring slow-setting materials three minutes, and quick-setting one minute, and with this paste fill the vessel flush. The material has commenced to set when the needle no longer penetrates to the bottom. In quick-setting materials the commencement of set can also be determined by the thermometer.

To determine the *time of setting*, the cake is removed from the vessel. Every hydraulic bond material can be said to have set when it has hardened so much that the standard needle no longer makes any impression. The time in which this degree of hardening occurs is called the *time of setting*.

Whether a material is to be classified as quick or slow-setting is determined by the beginning of set.

d. As a *preliminary test* for the determination of the time of setting, the cake test can be employed. For this 100 grammes of the material to be tested are mixed with water to a paste of normal consistency, and stirred three minutes if slow, and one minute if quick-setting; this paste is made into a paste of about 2 cm. thickness, and placed on a glass slab. The same is said to have set when it resists the finger nail under slight pressure.

e. Addendum.

It is desirable that the setting qualities be also determined with higher proportions of water than one necessary to make a paste of standard consistency.

β. For the determination of set of puzzuolano (trass), the following proposition is adopted:

The finely powdered puzzuolano dried at from 212° to 230° F. is heated to redness to determine the loss by weight of combined water; the commencement of set is determined by means of the standard needle of 1 sq. mm. (.00155 square inch) section, weighing 300 grammes (0.66 lb.) (see above, *α*, *c*), and when submerged in water of 59° F. as nearly as possible, but certainly with state-

ment of temperature, using a mixture of two parts by weight of puzzuolano (trass), one part powdered hydrate of lime, and one part of water. The mortar thus obtained is to be filled into the standard vessel and immediately submerged, and examined after two, three, four, and five days to determine with what load the above standard needle completely penetrates the cake, but the mould in this case must not have been more than 1.6 inch deep.

4. *Constancy of Volume.*

α Portland cement.

a. To obtain a rapid judgment of the constancy of volume of Portland cement when hardening under water or under conditions preventing drying, the simple baking test is to be resorted to, and as follows :

The cement is mixed with water to form a paste of standard consistency, and small cakes of from 8 to 10 cm. diameter and 2 cm. (3.15—3.94 inches diameter × .788 inch thick) in thickness are formed on flat glass plates.

Two of these cakes, which are guarded against complete drying to avoid shrinkage cracks, are placed after twenty-four hours, or at least after having set, with their smooth surfaces upon metal plates, and subjected to a temperature of from 230° to 248° F. (at least one hour) until no more steam is given off.

If the cakes after this treatment show neither warping nor cracks on the edges, the material can be considered to have constancy of volume ; otherwise the result of the now universal cake test on glass plates is to be made, and the result obtained is to be decisive.

In the presence of more than 3% of dry sulphate of lime (or a corresponding proportion of unburnt gypsum) the baking test is not conclusive.

b. The deciding test of constancy of volume is the cake test on glass plates, which is to be executed as follows :

One hundred grammes (0.22 lb.) of the cement to be tested are mixed with water, and made into a paste of normal consistency, and a cake thereof of about 2 cm. (0.788 inch thick) thickness is made on a plate of glass. Two of these cakes, guarded against drying, are submerged in water after twenty-four hours or when set, and the material is said to have constancy of volume when the cakes, after twenty-eight days' submersion, show neither warping nor cracking of edges.

c. The *cooking test* is to be considered as undoubtedly the most reliable and rapid test to determine constancy of volume for Portland cement, slag cement, and puzzuolano.

The following method of making the cooking test is referred to the Standing Committee for further investigation and report.

METHOD OF MAKING THE COOKING TEST.

Fifty grammes of the cement to be tested are mixed with about 13–15 *grammes of water to standard consistency and worked for one minute and then made up into the usual cakes on plates of glass* (0.4 *inch thick thinning down at the edges); then kept for twenty-four hours in a closed space, saturated with water, after which it is removed from the glass slab or else placed upon it into a cold water bath, which is gradually* (*in about* 10 *minutes*) *brought to the boiling point, while evaporation is prevented by a close fitting cover. The cake must be completely immersed in the boiling water; in case more water is to be added, it must be done in small quantities so that the water will immediately again come to boiling.*

The Standing Committee is recommended to investigate the methods of determining constancy of volume of mixtures of cement and sand.

Tests made by Professor Bauschinger showed that cements which had been found entirely satisfactory by the standard-cake test (not only after twenty-eight days, but also after one-half year and a whole year) showed swelling after one-half year by Bauschinger's apparatus, and in a marked and considerable degree even to the naked eye after one year. The test pieces were about 2 inches square and 4.8 inches long, mixture being 1:3.

β. Hydraulic limes and Roman cements.

For these the cake test, under water, as given under *α*, *b*, is recommended.

Determination of the value of the cooking test (*see ante*, *α*, *c*) *for these hydraulic mortars is intrusted to the Standing Committee.*

γ. Puzzuolano. (*Trass.*)

For these the following proposition is recommended:

a. A mixture of two parts by weight of puzzuolano (trass), one part of powdered hydrate of lime, and one part by weight of water are placed in a conical metal dish with a strong bottom, 1.2—1.6 inch depth and 2.4—3.2 inches diameter at the upper open end (galv. iron), is stroked off level, and immediately submerged to a depth of 0.8 inch in water. The mortar when set must not project over the edges of the dish, nor must it be shrunk below it. The dish must have a rigid bottom to compel all expansion to take place in an upward direction.

b. The *cooking test* is to be considered as undoubtedly the most reliable and rapid test for determining the constancy of volume of puzzuolano (trass). (See *ante*, *a*, *c*.)

5. *Tests of Strength.*

a. For all hydraulic bond materials, excepting puzzuolano:

a. The tests of strength are to be made with mixtures of 1 part by weight of the material, and 3 parts by weight of sand. It is, however, desirable to make tests with a larger admixture of sand as well.

b. The sand to be used is to be standard sand, obtained from the purest quartz sand. Standard sand in a limited sense—*i.e.*, such sand as that with which all comparisons are to be made—is the sand found at Freienwalde, which has been screened by sieves of 380 and 760 meshes per square inch.

Countries other than Prussia may obtain their own standard sand, and if possible of such character that it will give results of tests similar to those obtained by Freienwalde sand. If this is impossible, then appropriate co-efficients for comparison are to be determined.

c. The wires of these sand sieves are to be as follows:

Sieves of	60	120	meshes per sq. cm.
Diam. of wire,	0.38	0.32	mm.
	380	760	meshes per sq. inch.
	0.0096	0.0081	inch diam.

d. The weight by volume of the standard sand is to be determined by weighing the sand sifted into a standard liter measure.

e. The deciding test of resistance, determining its value, is the *compression test;* this is to be made with cubes of 50 sq. cm. (7.75 square inch) section.

f. The usual test of quality (test determining the quality of the material to be furnished) is the tension test, made by means of the German standard apparatus, with test pieces of the German standard form, having a section of 5 sq. cm. (0.775 square inch) at the part to be ruptured.

g. The determination of a standard consistency of mortars, as well as the discovery of a practical mechanical device for producing test pieces, which, in particular, insures equal density of compression and tension test pieces, is delegated to the new Standing Committee.

For the present all test pieces may be prepared by hand, having care to give them as nearly as possible equal density.

h. To carry out the tension and compression tests, six pieces of each age of mortar are necessary. The mean of the four highest results obtained is to be considered as the controlling one.

i. All test pieces must be kept in an air space saturated with watery vapor for the first twenty-four hours, after which, and until immediately before testing, submerged in water of a temperature 59°—65° Fahr., to be changed once every seven days.

k. The critical test for all bond materials is to be the 28-day test.

To judge of the quality in *less time* in the case of Portland cement, the resistance may be determined upon mortar of the composition of 3 : 1 after setting seven days.

The Conference of Vienna has decided, relative to testing cements in less than three days, that:

Tests of neat cement (Portland and slag cement) are not alone sufficient as a basis for correct determination of quality of these materials.

Tests made with sand-cement mixtures of 1 : 3 do not give a sufficiently safe knowledge of the full value of Portland and slag cements, but can at least serve as an approximate guide as to the value of the material, and the three days' test of sand mixtures is therefore recommended.

To this end the Conference recommends that only such machines be used for making test samples, as permit production of tension as well as compression samples in the same length of time, and while doing the same amount of work of ramming.

The standard sand to be used is, of course, to be pure quartz sand.

Instruments of precision are to be used in making compression tests.

Further development of propositions for rapid tests of other hydraulic bond materials is to be left with the Standing Committee, and special attention is to be given to chemical analyses. The value of the needle test (determination of the weight under which a needle or piston sinks a definite amount into the setting material), as well as of the effect of warm baths on rapidity of setting, is to be further investigated.

β. All *tests of resistance* of *puzzuolano mortars* are to be made on mixtures by weight of 2 parts puzzuolano, 1 part

powdered hydrate of lime, 3 parts standard sand, and 1 part of water. The treatment shall in other respects be the same as that of cement samples, and the puzzuolano mortars especially are to be kept in an air space saturated with watery vapor for 24 hours before being submerged.

For special tests the test pieces can be put under water immediately after making; in such cases it is recommended to increase the quantity of water by one-tenth when making the paste.

The observation of conditions of temperature is of greatest importance for puzzuolano mortars; if at all possible, the mixing and immersion water are to be kept at from 59° to 65° Fahr.

For test pieces of puzzuolano mortars only the purest air-slaked lime is to be used, as the strength depends largely upon the lime.

When builders manufacture their own puzzuolano from tufa, then the stone is to be so finely powdered for sampling that 75% will pass through the sieve of 900 meshes (5,732 per square inch), and 50% through the sieve of 4,900 meshes per square centimetre (31,170 per square inch), using wires of diameters stated above.

When powdering, no coarser particles are to be discarded, but the pulverization must be carried to such a point as to produce the prescribed fineness.

6. *Adhesion.*

Determination of proper methods of testing in which, if possible, the German standard tension test apparatus is to be used, is intrusted to the Standing Committee.

7. *Density of Different Hydraulic Bond Materials for the Preparation of Mortars.*

The density is determined by the well-known mortar volumemeters or mathematically by Stahl's method (which is given in the XIVth Part of the Mittheilungen aus dem mechan. techn. Laboratorium der kgl. techn. Hochschule, pp. 252 and 270).

8. *Effect of Sea-water on Hydraulic Bond Materials.*

In consequence of a paper presented by Professor Debray, at the Berlin Conference, the Standing Committee was charged with the following problem:

Determination of the effect of sea-water on hydraulic bond materials.

The report at the Vienna Conference developed a difference of opinion in regard to the shape of test pieces, as well as method of tests. Therefore the problem *was again turned over to the sub-committee, with the discretion of selecting a method. Very lean mortars in which very fine sand is used are also to be considered.*

In addition to the problems left in the hands of the Standing Committee, and indicated by italics in the foregoing pages, the following further work was turned over to the fourth Standing Committee by the Vienna Conference:

Determination of methods of testing materials at temperatures abnormally low, especially for iron and steel.

Determination of the effect of fecal matter on hydraulic bond materials.

Investigation of abnormal behavior of cements, especially in relation to time of setting.

In view of the fact that agreements of uniform methods of testing are not alone of great commercial value in the case of the more usual materials of construction, but also for other raw materials, which may be partly or wholly finished products; and, furthermore, as a distinct line defining materials of construction cannot be drawn; and, also, because many of the manufacturing concerns and testing laboratories represented at the conferences have habitually been occupied with tests of textile fabrics, paper, etc., etc., and upon which they possess valuable information, *the Standing Committee is to consider whether and in which manner uniform methods of testing for such important materials can be established by future conferences.*

DLII.

REPORT OF COMMITTEE ON A STANDARD METHOD OF CONDUCTING LOCOMOTIVE TESTS.

To the American Society of Mechanical Engineers:

The committee appointed at the Cincinnati meeting, held in May, 1890, to devise standard methods of conducting efficiency tests of locomotives, begs leave to submit its report as follows:

1. To keep pace with the rapidly growing interest in the improvement of the locomotive, efficiency tests have, within the past few years, come to be regarded, and rightfully so, as being fully as necessary for determining questions of economy and performance, as tests of stationary engines made for the same object. That the subject of locomotive economy, and the methods to be followed in determining it, is one of importance, is seen in the fact that the consumption of coal by locomotives in the United States amounts to over 50,000,000 tons per annum, or about one-third of the whole production of bituminous and anthracite coal in this country. A uniform system of making locomotive tests seems more to be desired than uniformity in conducting tests of any other class of engine, for the reason that locomotives are subjected to more widely varying conditions of work than any other motor in common use; and this fact doubtless explains the great variety of results heretofore obtained by different experimenters, and it furnishes reasons for inconsistencies which might not otherwise have occurred. It is the object of this report to standardize methods of testing, so that the results obtained from different engines, and those found by different observers, may be brought down to the same basis of comparison, so far as this can be done within the limitations imposed by locomotive service.

2. The two principal efficiency tests of a locomotive may be designated the "shop tests" and "road tests." The shop tests made by Professor Goss at the Purdue University, Lafayette, Ind., have proved so satisfactory, and the future possibilities are so promising, that the committee feels justified in giving it prominence in this report.

For determining satisfactorily many, if not all, questions bearing

upon the economy of the boiler and engine of a locomotive, or the relative economy of compound and simple locomotives, or the effect upon the economy produced by different classes of fuel and various methods of operation, the "shop test" is especially adapted, and it can be made with all the care and accuracy pertaining to tests of stationary plants. To determine questions of this character, therefore, the committee recommends that wherever possible resort be had to the uniform conditions of test which this method of trial, and this alone, affords. For determining other problems connected with locomotive service, and, in general, to ascertain the performance of the engine in regular work, the "road test" must be used.

Shop tests as distinguished from road tests involve the operation of the locomotive to be tested while jacked up, or otherwise arranged to allow the running of its mechanism without a corresponding movement of the locomotive as a whole. Such tests are recommended and their necessity is urged, because of the facility, when once provision is made for them, with which they may be conducted, the accurate methods of observation which they permit, and the means they furnish for investigating elements in locomotive performance which cannot be satisfactorily developed on the road. Shop tests will not make road tests unnecessary, for it is by the combination of both forms that the fullest information will be obtained; but it is evident that where such a combination is employed, many of the determinations made in the testing shed will apply to the conditions of the road, and that the road tests may, as a consequence, be much simplified.

In stationary practice the necessity for constant conditions during a test which is to serve any purpose beyond that of simply giving the power of the engine has long been recognized. For example, if the performance of two stationary engines is to be compared, the engines are tested under conditions similar in every particular; otherwise the comparison is not a fair one. Or if it is desired to study the effect of a change in the method of operating a given stationary engine, tests for comparison are made both under the normal and under the changed condition; but in both cases *all things* are the same save the *one* factor the effect of which is to be investigated. If this condition is not observed and the speed in one case is materially changed from that of the other, or if there is a difference of steam pressure, or a difference in the number of expansions, when neither of these factors constitutes the subject for

study, difference in the performance of the engine is as likely to be due to these variations as to the particular change the value of which is to be tested.

These recognized principles governing all experimental study of the action of stationary engines have, for obvious reasons, been difficult to apply in testing locomotives. A standard train, use of the same line, and adherence to schedule time, all as recommended in the following pages of this report, will do much for road tests in this direction. But when all precautions have been taken there still remain conditions which are variable in character, the effect of which it is well-nigh impossible to overcome.

The necessity for test work of a high order is emphasized by the fact that the real difference in the economy of different well-designed locomotives of the same size when employed in similar service is not great. This fact appears to remain true even when both simple and compound engines are included in the comparison. If the steam engineering problems involved could be worked out by tests which would leave no doubt as to what these differences are under the best possible conditions, locomotive designers would have a much more definite starting-point than at present, and the science of locomotive engineering would be materially advanced.

We understand that the predominating object of a standard method of "road test" is to ascertain the efficiency of a locomotive when engaged, as near as may be, in its normal work; that is, when hauling a train of cars over a route of considerable length. The test should, therefore, be made on a through train running over a route at least 100 miles long; and, when practicable, it should be a special train not hampered by an absolutely fixed time schedule. That the results may be comparative with those obtained from the same engine under various desired conditions of work, and with those obtained from other engines which it may be desired to subject to competitive trial, the same identical train and route should be made use of for the whole series of trials.

It may often be found desirable to determine the efficiency of an engine when engaged in regular schedule work, whether express, accommodation, or freight service, however much the performance may be affected by the special route over which the train is run, by the frequency and length of time absorbed in stops, by the handling of the fires while the engine is separated from the train at the terminal stations, and by other conditions which tend to reduce the economy. Such tests may be made to conform to the

recommended standards so far as it may be consistent with the object in view, and there seems to be no occasion for making special provision for them in this report.

It may often be desirable, also, to make partial tests of efficiency to ascertain, for instance, the relative economy of different fuels requiring simply evaporative tests of the boiler, or the economy of different conditions of working the cylinders which would require simply feed-water tests of the engine. These may also conform so far as necessary to the standard methods recommended for the complete efficiency test, no special provision for these being made here.

3. In making road tests we recommend that a dynamometer car be used, so as to obtain thereby the pull upon the draw-bar. By this means the useful work done by the locomotive is measured, and, what is more important, the record obtained is continuous and uninterrupted throughout the whole test. An exact average of the power used in hauling the train can thus be found, a result which has thus far been obtained by no other method.

4. We recommend, in general, that the locomotive test, whether made in the shop or on the road, be conducted with such completeness that all the information relating to the performance of both the boiler and cylinders be determined. With this object the data to be found embrace the weight of coal burned, its chemical analysis, its heat of combustion, the weight of ashes and cinders, the weight of water evaporated and that lost by overflow of the injector and otherwise, the moisture in the steam, the temperature of the escaping gases, the analysis of the gases, if thought desirable, the force of the draught, the pressure of the steam in the boiler and steam-chest, the number of revolutions of the drivers per minute, the indicated horse-power of the engine, the tightness of valves and pistons, and the pull on the draw-bar.

a. For a road test we advocate starting with a good fire, the actual thickness to be estimated, and burning it down to the same thickness and condition (as near as can be estimated) at the end of the run; the observations noted for the start being taken just before the time of beginning the run, and those noted for the stop, immediately after reaching the end of the trip. We realize that this method applied to the road test is not scientifically accurate, but it must be remembered that the rate of combustion in a locomotive fire-box is exceedingly high, and the error which occurs in estimating the thickness of the fire (should the observations be slightly erroneous) is far less serious than in stationary boilers

working at their usual slow rate, and under the circumstances this seems to be the best course to pursue.

b. For the measurement of the feed-water we advocate the employment of a reliable water meter, suitably calibrated at the time of use. Observations of this instrument can be made leisurely and at regular intervals, whether the locomotive is in motion on the road or at rest. The familiar method of tank or tender measurement must, on the other hand, be based on observations taken only at stopping-places, and these often in great haste. Although a meter is not always accurate, it is believed that for the purposes in view it is much less subject to error than observations made at the tank. The meter observations should, however, be checked by tank measurements made at all water stations.

The apparent weight of water fed during a certain period must be corrected for differences in the quantity of water in the boiler at the beginning and end of the period, but in making this correction, which must be done by observing the positions of the water line in the glass water-gauge, it is important that these positions should first be corrected for the inclination of the boiler, and measurements at the tank should likewise be corrected for the inclination of the tender.

c. The weight of ashes and cinders found on the road test furnishes little indication of the actual amount of ash and unburnt matter in the fuel, on account of the great chance of loss through the stack, due to the effect of the forced draught. It is desirable, however, to obtain these weights, as they often furnish some indication of the character of the fuel. The percentage of ash, from which the quantity of combustible is found, should be obtained from the calorimeter test of the coal.

d. Recent progress in the determination of the heating value of coal, by the use of some form of oxygen calorimeter, has been so satisfactory that the relative quality of different coals can now be readily and definitely measured. It is fully as important to know the character of the fuel as to find the number of pounds of coal burned, and no test can be satisfactory that leaves out the heat value of the fuel. Chemical analysis of the coal is desirable, and it gives much useful information, but it is believed that the heat test is of greater value.

e. The introduction and development of the wire-drawing calorimeter, with or without separating apparatus, has made the determination of moisture in the steam, especially on locomotives, a com-

paratively simple matter. No reason now exists for omitting the calorimeter test for want of a suitable instrument. The committee has no recommendation to make regarding the exact form of calorimeter to be used, but advises careful attention to the well-proved methods elsewhere referred to.

f. It is of the greatest importance in analyzing the results of a locomotive test to have definite knowledge in regard to the tightness of the valves and pistons. If leakages are known to exist, an explanation is often furnished of results which would otherwise appear inconsistent. The tightness of the valves and pistons can be determined when the engine is at rest, and the committee recommends that this trial be made in connection with every test. There is excellent ground for the belief that if an engine is found to be tight when at rest, it will be tight when in action; and, on the other hand, if it is found to be leaking when at rest, it will likewise leak to a greater or less extent when at work.

5. We recommend, for a standard basis on which to compare the efficiency of locomotives, the number of pounds of standard coal burned per dynamometer horse-power per hour. The term "standard coal" refers here to coal in which the total heat of combustion, as determined by an oxygen calorimeter, is 12,500 British Thermal Units per pound. The unit 12,500 B. T. U. is selected, partly on account of its numerical simplicity, and partly because it represents the total heat of the average grades of coal used in the United States.

To convert the actual amount of coal used into the equivalent weight of "standard coal," the weight of coal burned is multiplied by the total heat of combustion of the coal, and the product is divided by 12.500. *

We advocate this unit of standard coal, believing that it is extremely desirable to refer the efficiency of different engines to a coal basis. In view of the practical difficulty of always testing locomotives with the same kind of fuel, the method of correction given above is recommended. This method of correction recommended may be regarded as to some extent approximate, but we believe

* This assumes that the proportion of the total heat which is utilized in the locomotive is the same for the standard coal as it is for the coal actually used.

As an illustration of the method of computation, suppose a locomotive uses 5 lbs. of coal per dynamometer horse-power per hour, and the coal gives on the calorimeter test a total heat of combustion of 10,000 B. T. U. The product of this into the weight of coal burned is $10,000 \times 5 = 50,000$, which, divided by 12,500, gives 4 lbs. as the equivalent weight of standard coal.

the comparative results obtained by its use will be all that can be desired.

The consumption of standard coal is referred to the dynamometer horse-power, that is, the power obtained from the pull on the draw-bar; first, because the dynamometer horse-power is a correct average record of the power developed; and, second, it is the useful work done by the engine.

In selecting standard coal and dynamometer horse-power as the leading units of comparison, we do not under-rate the desirability of expressing the performance in terms which are commonly used, and in any other terms which may render the results complete, and these should be made a part of the report. Of these we recommend for purposes of comparison the weight of coal and water, and the number of heat units of the steam consumed per indicated horse-power per hour; the same, referred to the dynamometer horse-power; the weight of actual coal and standard coal referred to the ton mile of total load and the ton mile of train load; and the number of pounds of water evaporated per pound of coal. With these results the performance of the locomotive may be studied in all its bearings.

We are aware that the proposed standard units of comparison are not in accord with those adopted by the Committee on Duty Trials of Pumping Engines. The boiler and engine which constitute a locomotive are more closely identified as one complete machine than the boiler and engine of a pumping plant, and the need of separate treatment of the two functions of steam generation and its subsequent use, which applies to pumping engines, is of less importance in locomotive work.

6. Having made the foregoing explanation of the principles which have guided us, we now beg to submit in the following pages the standard methods of locomotive testing which we recommend. We have conferred with a committee appointed for a similar object by the American Railway Master Mechanics' Association, and a preliminary report was presented to that Association at the meeting held in Lakewood, N. Y., June 19, 1893.

Respectfully submitted,

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STANDARD METHOD OF CONDUCTING EFFICIENCY TESTS OF LOCOMOTIVES.

I. PREPARATIONS FOR TEST, AND LOCATION OF INSTRUMENTS.*

A. The locomotive should be put in good condition preparatory to the test. The boiler and tubes should be tight, and both the interior and exterior surfaces should be clean, and, if possible, free from scale. There should be no lost motion in the valve gear, and the valves should be set properly. No change in the engines should be allowed during the progress of a series of tests, unless so ordered for the purposes of the trial.

A glass water-gauge should be fitted to the boiler, if not already provided. A rod should be attached to the reversing lever and carried forward to the front end of the boiler, where a graduated scale is provided and suitably marked, so that the position of the reversing lever can be seen at a glance by the person taking indicator diagrams. The throttle-valve lever should be provided with a scale, to show the degree of opening of the throttle.

B. The valves and pistons should be tested for leakage with the engine at rest. The steam valve can be tried by setting the engine so that the valve on one side will be at the centre of its throw, in which position both ports are usually covered, and pulling open the throttle valve, blocking the drivers if there is a tendency for the engine to be set in motion. Leakage of the valve, if any occurs, will show itself by escaping at the smoke-stack, or at the open drain-cocks. The tightness of the piston may be tested by setting the engine so that it takes steam, blocking the drivers, and opening the throttle valve. This should be tried first on one cylinder and then on the other, and, if desired, it may be tried with the pistons at various points in the stroke. The leakage, if any occurs, will be shown either at the top of the smoke-stack or at the open drain-cock.

C. The following instruments should be verified, or calibrated: steam-gauges, draught-gauge, pyrometer, thermometers for calorimeter and feed-water, water meter, tank, revolution counter, indicator springs, dynamometer springs, and dynamometer recording

* The directions here given apply largely to both shop and road tests, but especially to the latter.

mechanism. The radiation loss on the steam calorimeter should be determined, or the normal readings ascertained; * and the quantity of steam which passes through the instrument in a given time should be measured.

D. The quantities of steam consumed by the air-pump, the blower, and the whistle, under conditions of common use, should be determined, thereby obtaining data by which to correct for the steam thus used. This can best be determined for each one by observing the fall of water in the gauge glass when no steam is drawn from the boiler for any other purpose; the quantity being computed from the data thus found, and the dimensions of the boiler. The leakage of the boiler should also be found, using the same method.

E. To facilitate the measurement of coal and the determination of the quantity used during any desired period of the run, it is desirable to provide a sufficient number of sacks of a size holding a weight of, say, 100 lbs., and weigh the coal into these sacks preparatory to starting on the test. If desired, the sacks may be numbered, to facilitate the accuracy of record.

F. The instruments and other apparatus that should be provided, and their locations, are as follows:

To facilitate the work of operating the indicators and reading the instruments at the front end, the smoke box should be surrounded with a wooden fence, or "pilot box," as it may be called, resting on the top of the cow-catcher and extending back far enough to enclose also the sides of the cylinders. This box is floored over, and the enclosure thus provided forms a convenient place for the accommodation of the assistants at this end of the locomotive, and it affords them some measure of protection against wind and rain, as also the jolting and vibrations due to rapid travel.

A special steam-gauge with a long siphon is to be used for registering the boiler pressure. It can best be located on the left-hand side of the cab.

The indicator apparatus which is most suitable consists of a three-way cock for the attachment of the indicators, and some form of pantograph motion for the driving rig. The pipes leading from the cock to the cylinder should be three-fourths inch diameter inside, and they should connect into the side of the cylinder rather than into the two heads. The indicator should also be piped so that a steam

* *Transactions A. S. M. E.*, Vol. XI., p. 793.

chest diagram can be drawn by it. Sharp bends in the pipe should be avoided, and they should be well covered, to intercept radiation. The three-way cock should be provided with a clamp rigidly secured to the cylinder, and thus overcome any tendency of the indicators to move longitudinally with reference to the driving rig. Absolute rigidity is highly essential in this particular. Two forms of pantograph motion are shown in Figures 458 and 459. In both of these the reduced motion is transmitted to the indicator through a light rod, working horizontally. By this means a cord eight or ten inches

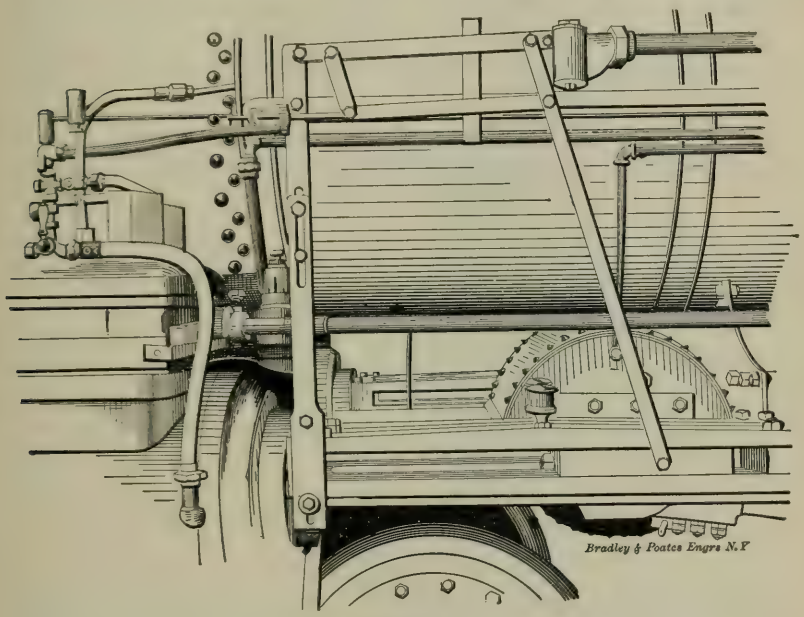


FIG. 458.

in length is sufficient for connection to the indicator. Care should be taken to set the instrument in such a position that the cord pin in the end of the rod travels in a direction pointing to the groove in the paper drum. Pantograph motions arranged as noted are preferable to the common pendulum and quadrant reducing mechanism, with its long stretch of cord.

A draught gauge consisting of a U tube containing water, properly graduated in inches, should be connected to the smoke box and attached to the side of the pilot box.

A pyrometer for showing the temperature of the escaping gases should be used in a position below the tip of the exhaust nozzles.

The calorimeter should be attached either to the steam dome at a point close to the throttle opening, or to the steam passage in the saddle casting on one side, according as it is desired to obtain the character of the steam at one point or the other. The former location is preferred by the committee. A perforated half-inch pipe should be used for sampling and conveying the steam to the calorimeter pipe. For descriptions of various forms of calorimeters which are adapted to locomotive use see *Trans. A. S. M. E.*, Vol. X., p. 327; Vol. XI., p. 790; Vol. XII., p. 825.

The water meter should be attached to the suction pipe of the injector, and located at a point where it can be conveniently read when the locomotive is running. It should be provided with a

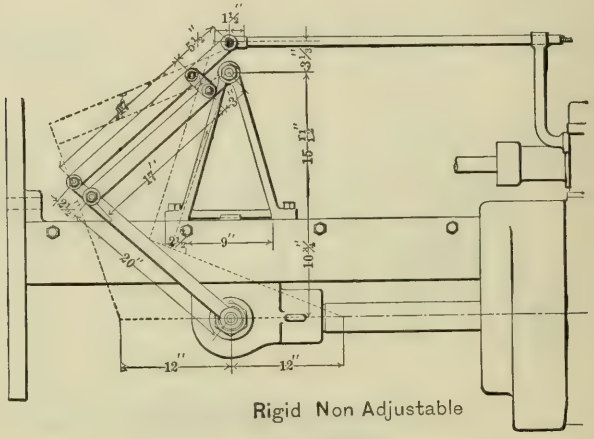


FIG. 459.

check valve to prevent hot water from flowing back through it from the injector, and a strainer to intercept foreign material.

To measure the depth of the water in the tank, a metallic float should be used, carrying a vertical tube which slides upon a graduated rod, the lower end of which rests upon the bottom of the tank. This should be placed at the centre of gravity of the water space. If the desired location cannot be used, provision should be made for ascertaining the level or inclination of the tank. The best device for this purpose is a plumb-line of a certain known length provided at the bottom with a double horizontal scale having one set of divisions parallel to the side of the tank, and the other set at right angles to it. From the readings on these scales referred to the length of the line, the level of the tank in both directions can

be ascertained. A similar device should be attached to the boiler to correct for the variation in its inclination. The plumb-line may be conveniently attached for this purpose at some point near the front end.

The revolution counter should be placed near the front end of the engine in plain view from the pilot box. It is operated through a belt from the driver shaft. This recommendation applies to that form of counter which shows at a glance the exact speed in revolutions per minute.

A stroke counter should be provided for showing the number of strokes made by the air-pump.

Electric connection should be made between the dynamometer car and the pilot box, so that dynamometer records and indicator diagrams may be taken simultaneously. Another desirable provision is a speaking tube leading from the dynamometer car to the locomotive cab, and one also to the pilot box.

G. It is needless, except for a complete record of directions for preparatory work, to call attention to the desirability of having the test, and especially the road test, made under the supervision of a competent person, who is not only familiar with the details of testing, but also with the proper method of firing and mechanical operation of the locomotive. This is a most important factor, for it is only the clear-headed and able experimenter who is likely to obtain satisfactory work in this most difficult department of engineering tests.

In the matter of assistants, the conductor of the test is best able to judge as to the number required, the various duties of the different men, and the manner of taking records. A good test can be made with eight (8) assistants, distributed in the manner indicated in the following list, which gives their duties:

Two (2) cab assistants, who read the steam-gauge, the position of the throttle-valve and reversing lever, the water meter, the height of water in the tank, the height of water in the glass water-gauge, the level of the tank, the number of times the whistle is blown, the length of time the safety-valve blows, the length of time the blower is in action, the reading of the air-pump counter, the temperature of the feed-water in the tank, the time of starting and stopping the injector, the time of opening and closing the throttle-valve, and the number of sacks of coal used. These two observers have previously checked the weights of coal placed in the sacks.

Three (3) pilot-box assistants, one of whom reads the pyrometer,

the draught-gauge, the steam-chest gauge, the revolution counter, and marks on the indicator diagrams the time, position of reversing lever, steam-chest pressure, and revolutions per minute. He also takes the levels of the boiler at stopping places. The other two observers are stationed at the cylinders and manipulate the indicators, one being employed on each side.

One (1) calorimeter assistant, who reads the calorimeter thermometers, and the gauges connected with the instrument, if these are employed.

Two (2) dynamometer car assistants, who record time of each start and stop, time of passing each station and each mile-post, time of taking each indicator diagram as obtained from signals of the indicator men, and all these readings are marked so far as possible on the dynamometer paper. One of these men also assists the cab observer in reading the tank depth and its levels at stopping places. These men also keep a record of the direction and force of the wind, and the temperature of the atmosphere.

An additional assistant is required if the gases are sampled and analyzed.

H. It is of paramount importance, after the complete preparatory work has been accomplished, that the locomotive be subjected to a preliminary run, of sufficient duration to make a fair trial of the testing apparatus, and to give the various assistants an opportunity to become trained in their duties.

I. SHOP TEST.

A. Preparation and Location of Instruments.

In preparing for a shop test the preparations described in Section I. should be followed so far as the nature of the test requires. When run as a stationary engine the locomotive is not circumscribed by the conditions of road service, and many provisions required on the road are unnecessary. It is unnecessary to determine the quantity of steam consumed by the whistle and air-pump, for these are not brought into use on the shop test; and no occasion exists for finding the quantity lost at the safety valve, for on the continuous shop run the steam pressure can be maintained at a uniform point, and blowing off readily prevented. It is unnecessary to use sacks for the convenient measure of coal, because the coal can be readily weighed up in lots as fast as needed for the test. It is unnecessary to provide a "pilot box," and no fixed location of

the instruments is required, as on the road test. The feed-water may be weighed before it is supplied to the tank, and the tank may be used in this case as a reservoir, the float showing its depth. The meter would thus be unnecessary as the principal instrument of measurement, but a meter is in all cases useful as a check upon this most important element in the data. The long indicator pipes required on the road test may be dispensed with, and one indicator applied close to each end of the cylinder—a practice much to be preferred to the use of a three-way cock and the single indicator. The dynamometer car is not required, but its equivalent should be provided, consisting of a dynamometer which registers the pull on the draw-bar, in the same manner as the device used on the road.

The number of assistants required on a shop test is less than that needed for a road test. A good test can be made with four (4) assistants, distributed as follows:

One (1) assistant for operating indicators.

One (1) assistant for measuring water.

Two (2) assistants for general observations and coal measurement.

If the gases are sampled and analyzed, one more assistant is required.

B. Conditions of Test.

The test should be continued for a run of at least two (2) hours from the time normal conditions have been established.

At the close of the test the water height in the boiler, and the height of water in the tank, should be the same as at the beginning, or proper corrections made for any differences which may exist.

The fire-box and ash-pit are then cleaned, and such unburnt coal as may be contained in the refuse is separated, weighed, and deducted from the total weight of coal fired. The balance of the refuse is weighed, as also the cinders removed from the smoke box.

During the progress of the test samples of the various charges of coal should be obtained, and at its close a final sample of these should be selected, dried, and subjected to chemical analysis and calorimeter test. The weight of the sample is taken before and after drying, to ascertain the amount of moisture contained in the fuel.

C. The Data and Results.

The data and results of the shop test can best be arranged in the manner indicated in Table No. 1. So far as these are in common

with the data and results obtained on the road test, the forms used on both kinds of test are identical.

TABLE NO. 1.

DATA AND RESULTS OF SHOP TEST ON .....ENGINE, MADE ... .189..

General dimensions, etc. (to be accompanied by a complete description, with drawings and full dimensions.)

1. Kind of engine.....
2. Size and clearance of cylinders.....
3. Area of heating surface.....
4. Area of grate surface.....
5. Diameter of exhaust nozzles.....

	Whole Run.
TOTAL QUANTITIES.	
6. Duration.....hrs.	.....
7. Weight of dry coal burned, including .4 weight of wood...lbs.	.....
8. Weight of water evaporated corrected for moisture in the steam.....lbs.	.....
9. Weight of ashes and refuse from ash pan..... "	.....
10. Weight of cinders from smoke box..... "	.....
11. Percentage of ash, as found by calorimeter test .....%	.....
12. Total heat of combustion per lb. coal as found by calorimeter test.....B.T.U.	.....
POWER DATA.	
13. Mean effective pressure, high-pressure cylinders.....lbs.	.....
14. Mean effective pressure, low-pressure cylinders..... "	.....
15. Average revolutions per minute.....rev.	.....
16. Indicated horse-power, high-pressure cylinders.....H.P.	.....
17. Indicated horse-power, low-pressure cylinders..... "	.....
18. Indicated horse-power, whole engine..... "	.....
19. Pull on draw-bar.....lbs.	.....
20. Dynamometer horse-power.....H.P.	.....
AVERAGES OF OBSERVATIONS.	
21. Average boiler pressure.....lbs.	.....
22. Average steam-chest pressure..... "	.....
23. Average temperature of smoke box.....deg.	.....
24. Average draught suction.....in.	.....
25. Average temperature of feed-water.....deg.	.....
26. Average temperature of atmosphere..... "	.....
27. Average percentage of moisture in the steam.....%	.....
28. Maximum percentage of moisture in the steam.....%	.....
HOURLY QUANTITIES.	
29. Weight of dry coal burned per hour.....lbs.	.....
30. Weight of dry coal burned per hour per square foot of grate surface.....lbs.	.....
31. Weight of coal burned per hour per square foot of heating surface.....lbs.	.....

TABLE NO. 1.—*Continued.*

	Whole Run.
32. Weight of water evaporated per hour .....lbs.	.....
33. Equivalent weight of water evaporated per hour with feed-water at 100° and pressure at 70 lbs.....lbs.	.....
34. Equivalent weight of water from 100° at 70 lbs. evaporated per square foot of heating surface.. .....lbs.	.....
PRINCIPAL RESULTS, COMPLETE ENGINE AND BOILER.	
35. Coal consumed per I.H.P. per hour.....lbs.	.....
36. Coal consumed per dynamometer horse-power per hour.... "	.....
37. Weight of "standard coal" consumed per I.H.P. per hour.. "	.....
38. Weight of "standard coal" consumed per dynamometer horse-power per hour..... ....lbs.	.....
BOILER RESULTS.	
39. Water evaporated per pound of coal.....lbs.	.....
40. Equivalent evaporation per pound of coal from and at 212°. "	.....
41. Equivalent evaporation per pound of combustible from and at 212° .....lbs.	.....

CYLINDER DATA.

42. Mean initial pressure above atmosphere..... lbs.

	H. P. Cyl.	L. P. Cyl.
43. Cut-off pressure above zero.....lbs.	.....	.....
44. Release pressure above zero..... "	.....	.....
45. Compression pressure above zero..... "	.....	.....
46. Lowest back pressure above or below atmosphere..... .....lbs.	.....	.....
47. Proportion of forward stroke completed at cut-off .....lbs.	.....	.....
48. Proportion of forward stroke completed at release .....lbs.	.....	.....
49. Proportion of return stroke uncompleted at compression.....lbs.	.....	.....

TABLE NO. 1.—*Continued.*

CYLINDER RESULTS.

51. Total water consumed per indicated horse-power per hour corrected for moisture in steam..... lbs.
52. Water consumed per I. H. P. per hour by cylinders alone (from line 51 less all measured losses)..... lbs.

	H. P. Cyl.	L. P. Cyl.
53. Steam accounted for by indicators at cut-off...lbs.	.....	.....
54. Steam accounted for by indicators at release.. "	.....	.....
55. Proportion of feed water used by cylinders (line 52) accounted for at cut-off.....lbs.	.....	.....
56. Proportion of feed water used by cylinders accounted for at release.....lbs.	.....	.....

Reports should give copy of a set of sample indicator diagrams, also combined diagram (in case of multi-expansion engine) and a chart showing graphically the principal data.

III. THE ROAD TEST.

A. Preparation and Location of Instruments.

The preparations required for the road test, and the proper location of instruments for the purpose, are fully described in Section I., and repetition is unnecessary.

B. The Dynamometer Car.

With a suitable dynamometer car the force required to move the train, or the pull upon the draw-bar, is registered upon a strip of paper travelling at a definite rate per mile. The scale upon which this diagram is drawn should be as large as is possible within reasonable limits; a scale of $\frac{1}{4}$ inch per 1,000 lbs. pull being suitable, as the maximum registered pull rarely exceeds 30,000 lbs. The height of the diagram should be measured from a base line drawn upon the paper by a stationary pen, so located that when no force is exerted upon the draw-bar the base line should coincide with zero pull.

The apparatus should be arranged to make a record of time marks in connection with the curve showing the pull. A chronometer should be provided, having an electric circuit breaker, by means of which a mark is made on the dynamometer paper every five (5) seconds. A better apparatus may be used in which a con-

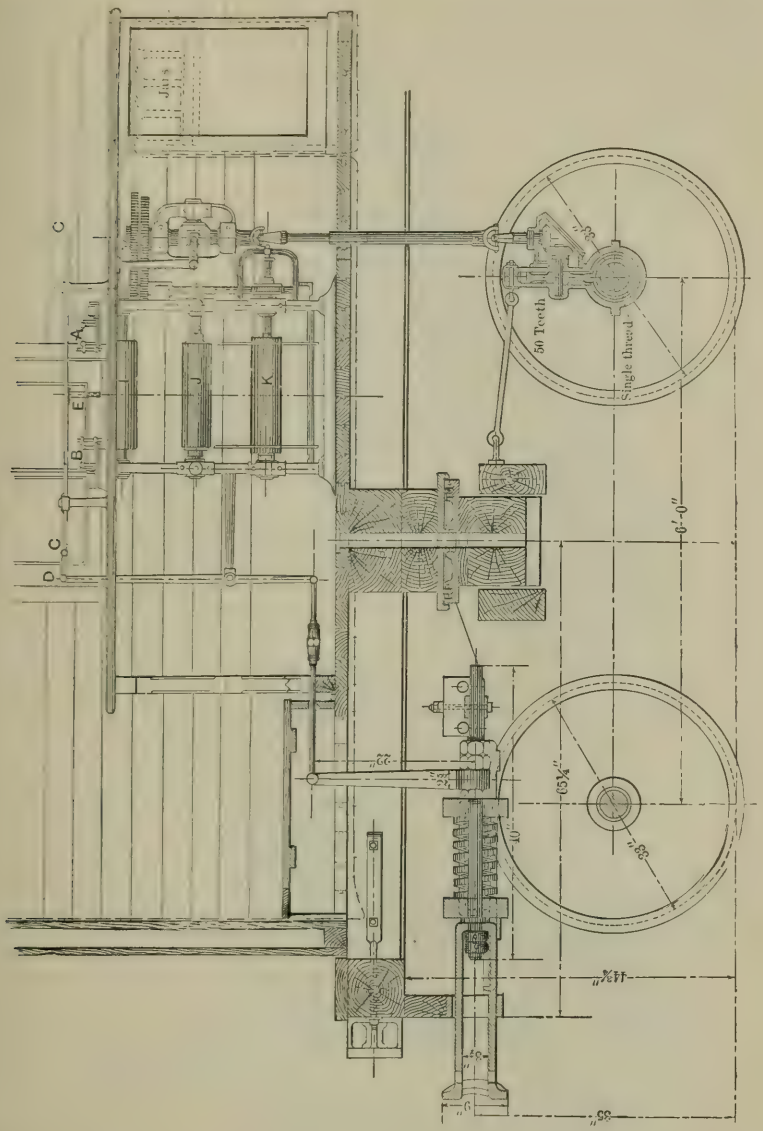


FIG. 460.

tinuous speed curve is traced upon the paper, parallel to the curve of pull. The ordinates of this curve, measured from a base line, give the speeds desired.

The location of mile-posts and other points along the route should be fixed upon the dynamometer paper by employing an

additional pen, and operating it by means of electric press buttons, which are placed at convenient points in the car.

As already noted, a similar device should be provided for mark-

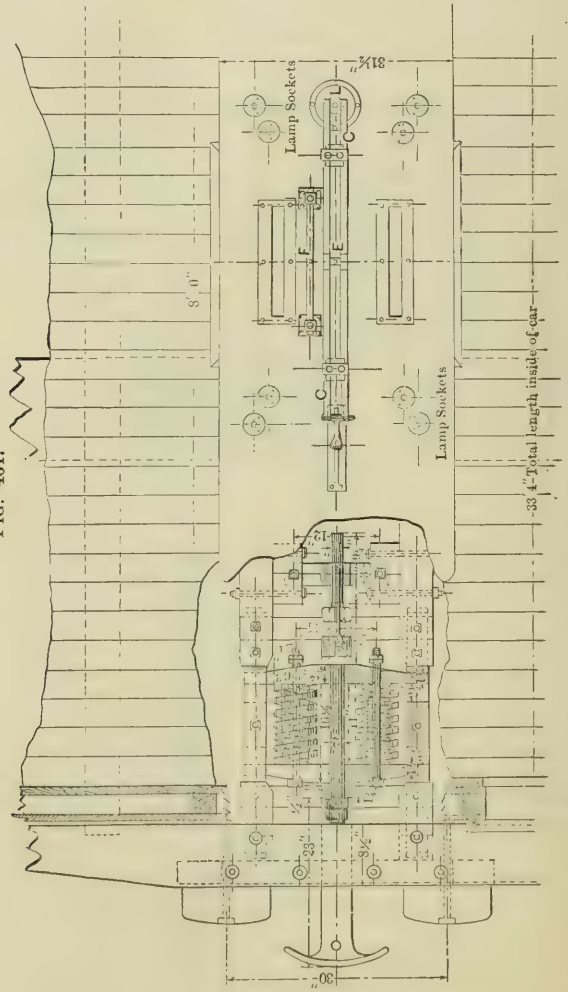


FIG. 461.

ing upon the dynamometer paper the time of taking indicator diagrams.

The rate of travel of the paper per mile should be such that one inch measured upon the diagrams represents 100 feet for short distance work, and for long distance work $\frac{1}{2}$ inch or $\frac{1}{4}$ inch should be

FIG. 462.

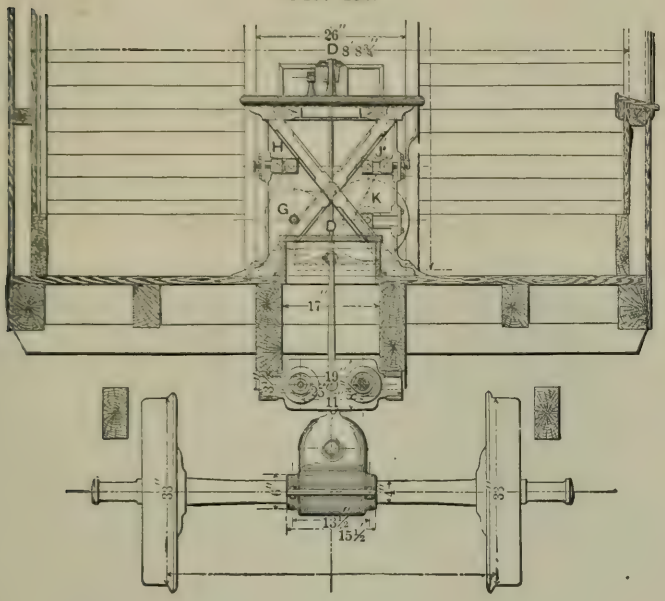
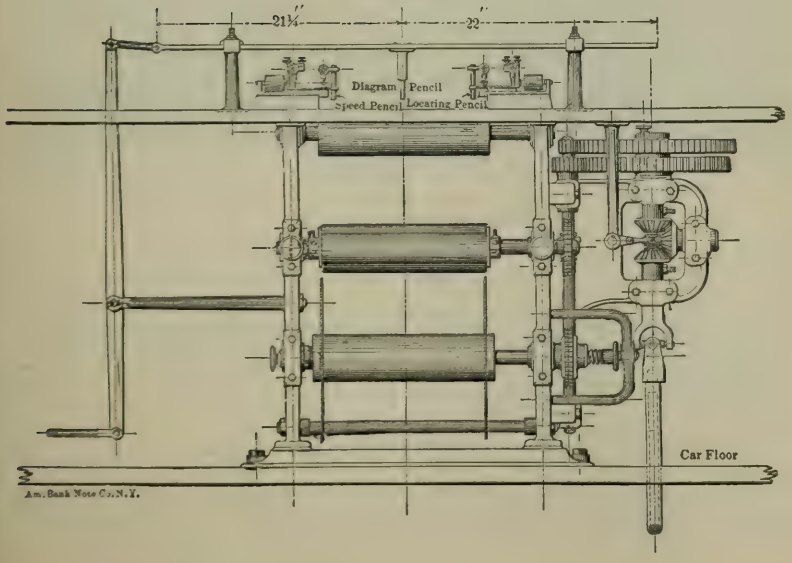


FIG. 463.



used to represent 100 feet of track. The driving mechanism for the paper should be so arranged that it can be changed to give these three proportions. It is necessary to have all the registering pens located upon the same transverse line at a right angle with the direction of the movement of the paper, in order that simultaneous data may be recorded.

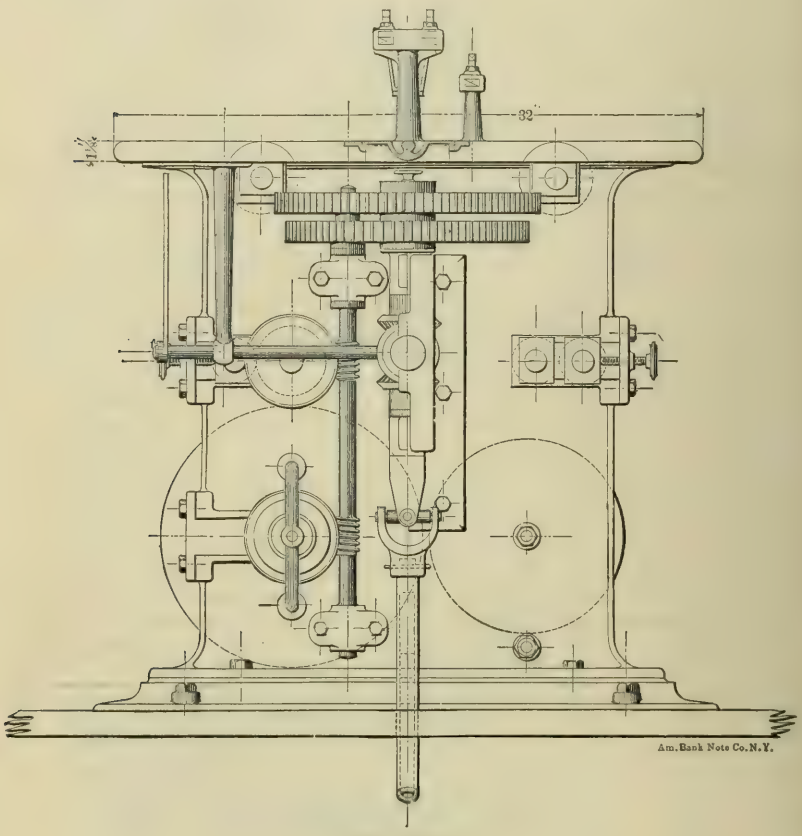


FIG. 464.

Figures 460 to 466 show the arrangement of apparatus in the dynamometer cars used by the P. RR., C., B. & Q. RR., & C., M. & St. P. RR.

C. Method of Conducting the Road Test.

The locomotive having been brought to the train, the steam pressure being at or near the working point, the fire being clean

and in good condition, though not over 4 to 6 inches thick, the ash-pan being also clean; observations are taken, say five (5) minutes before starting time, of the thickness and condition of the fire, the height of water in the boiler, the depth in the tank, the levels, the water meter, and the air-pump counter; and thereafter the regular observations are carried forward, and coal is fired from the weighed sacks.

Indicator diagrams should be taken as frequently as possible, the intervals between them being not over two minutes.

Other regular observations should be taken at close intervals.

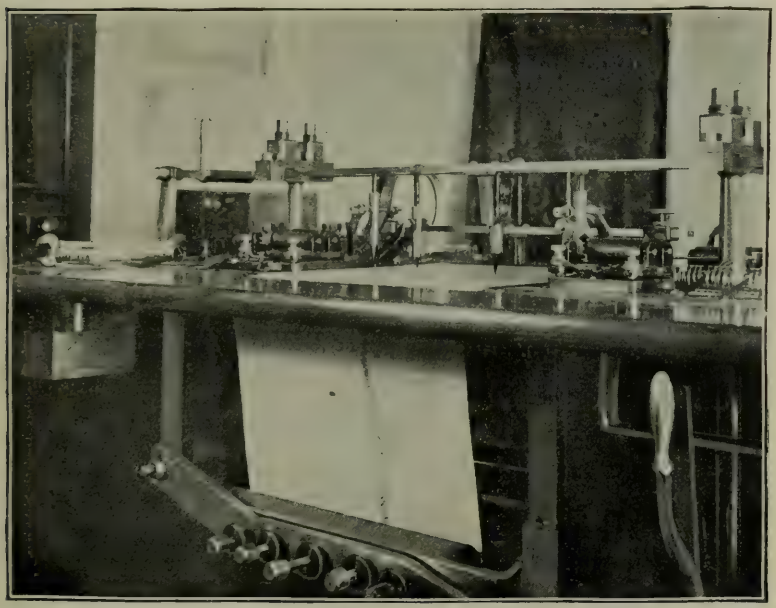


FIG. 465.

Calorimeter readings, when taken, should be continued for at least five (5) minutes at one minute intervals.

At water stations careful records should be obtained of water heights and levels of boiler and tank.

As the end of the route is approached, the fire should be burned down so as to leave the same amount and the same condition as at the start. When the end is finally reached, the fire should be raked, and its condition carefully noted. If it differs from that which obtained at the beginning, an estimated allowance must be made for such difference.

At the close of the test the height of water in the boiler should be the same as at the beginning, or, if not, the difference, corrected for inclination of the boiler, should be allowed for.

During the process of weighing the coal into the sacks numerous samples should be obtained, and a final sample of these selected. This is to be dried and subjected to chemical analysis and calorim-

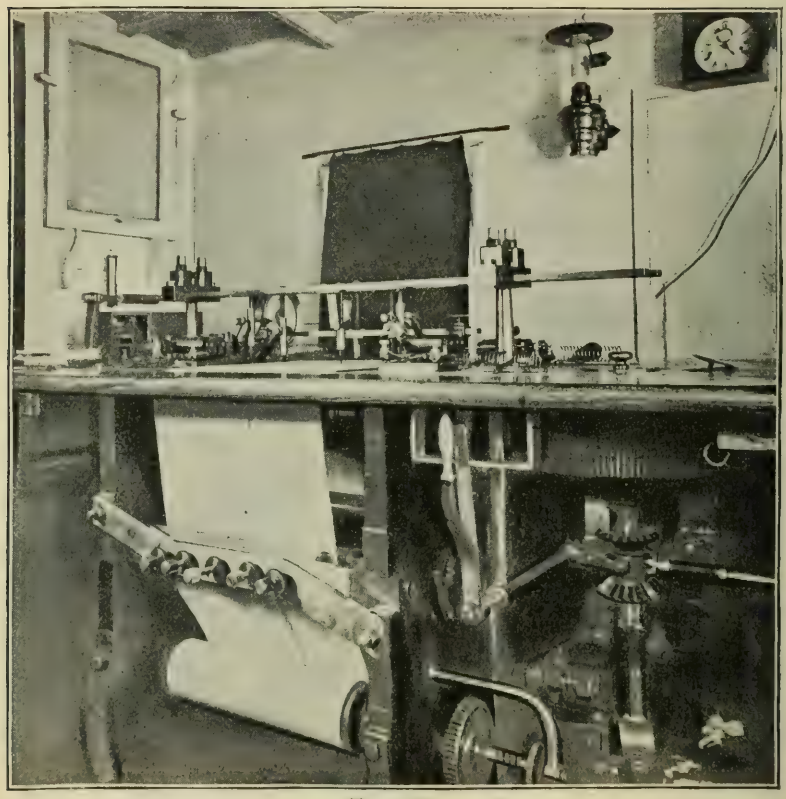


FIG. 466.

eter test. The sample is weighed before and after drying, and data obtained for determining the weight of dry coal used during the test.

The duration of the road test is the length of time which the throttle-valve is open.

D. The Data and Results.

The data and results of the road test may be tabulated in the form given in Table No. 2. This form corresponds in general with that recommended for the shop test; viz., Table No. 1.

TABLE NO. 2.

DATA AND RESULTS OF ROAD TEST ON.....ENGINE, MADE.....189..

General dimensions, etc. (to be accompanied by a complete description of engine with drawings and dimensions, also of train and route).

1.	Kind of engine.....	
2.	Size of cylinders.....	
3.	Clearance of cylinders.....	%
4.	Area of heating surface.....	sq. ft.
5.	Area of grate surface.....	sq. ft.
6.	Size of exhaust nozzles.....	inches.
7.	Average weight of locomotive and tender (including water)..	tons.
8.	Number of cars.....	
9.	Weight of cars.....	tons.
10.	Length of route.....	miles.
11.	Number of ton miles of train load.....	ton miles.
12.	Number of ton miles of total load.....	ton miles.
13.	Schedule time of trips.....	

TOTAL QUANTITIES.

14.	Duration or time throttle-valve is open.....	hours.
15.	Weight of dry coal burned.....	lbs.
16.	Weight of water evaporated corrected for moisture in the steam and loss at injector *.....	lbs.
17.	Weight of ashes and refuse from ash pan.....	lbs.
18.	Weight of cinders from smoke box.....	lbs.
19.	Percentage of ash as found by coal calorimeter test.....	%
20.	Total heat of combustion as found by calorimeter test	B.T.U.
21.	Results of chemical analysis of coal	

POWER DATA.

22.	Mean effective pressure, H. P. cyls.....	lbs.
23.	Mean effective pressure, L. P. cyls.....	lbs.
24.	Average revolutions per minute.....	rev.
25.	Indicated horse-power, H. P. cyls.....	H.P.
26.	Indicated horse-power, L. P. cyls	H.P.
27.	Indicated horse-power, whole engine.....	H.P.
28.	Pull on draw-bar	lbs.
29.	Dynamometer horse-power.....	H.P.

AVERAGES OF OBSERVATIONS OF INSTRUMENTS.

30.	Average boiler pressure.....	lbs.
31.	Average steam-chest pressure.....	lbs.
32.	Average temperature of smoke box.....	°
33.	Average draught suction.....	"

* Should be corrected for steam used by calorimeter, air pump, blower, safety valve, and whistle, to find cylinder results—line 56.

34. Average temperature of feed-water..... °
35. Average temperature of atmosphere..... °
36. Average percentage of moisture in the steam..... %
37. Maximum percentage of moisture in the steam..... %
38. Weather, wind, etc.....

OTHER DATA.

39. Average position of throttle.....
40. Average position of reversing lever.....
41. Average speed in miles per hour.....
42. Maximum speed in miles per hour .....
43. Number of stops.....
44. Average number of strokes of air pump per minute. .....
45. Total estimated weight of steam used by air pump per hour. lbs.
46. Estimated loss of steam at safety valve per hour..... lbs.
47. Estimated loss of steam at whistle per hour..... lbs.
48. Estimated weight of steam used by blower per hour..... lbs.
49. Estimated loss of steam at calorimeter per hour..... lbs.

HOURLY QUANTITIES.

50. Weight of dry coal burned per hour..... lbs.
51. Weight of dry coal burned per hour per square foot of grate surface..... ..... lbs.
52. Weight of coal burned per square foot of heating surface... lbs.
53. Weight of water evaporated per hour..... lbs.
54. Equivalent weight of water evaporated per hour with feed-water at 100° and pressure 70 lbs..... lbs.
55. Equivalent weight of water from 100° at 70 lbs. evaporated per square foot of heating surface..... .. lbs.
56. Weight of water consumed by engine cylinders (line 53, less sum of lines 45, 46, 47, 48, and 49)..... ..... lbs.

PRINCIPAL RESULTS—COMPLETE ENGINE AND BOILER.

57. Coal consumed per I.H.P. per hour..... lbs.
58. Coal consumed per dynamometer horse-power per hour..... lbs.
59. Coal consumed per ton mile of train load ..... lbs.
60. Coal consumed per ton mile of total load. ..... lbs.
61. Weight of standard coal consumed per I.H.P. per hour..... lbs.
62. Weight of standard coal consumed per dynamometer horse-power per hour..... lbs.
63. Weight of standard coal consumed per ton mile of train load lbs.
64. Weight of standard coal consumed per ton mile of total load lbs.

BOILER RESULTS.

65. Water evaporated per pound of coal..... ..... lbs.
66. Equivalent evaporation per pound of coal from and at 212° lbs.
67. Equivalent evaporation per pound of combustible from and at 212°... .... lbs.

CYLINDER DATA.

68. Mean initial pressure above atmosphere..... lbs.

	H. P. Cyl.	L. P. Cyl.
69. Cut-off pressure above zero..... lbs.		
70. Release pressure above zero..... lbs.		
71. Compression pressure above zero..... lbs.		
72. Lowest back pressure above or below atmosphere..... lbs.		
73. Proportion of forward stroke completed at cut-off,		
74. Proportion of forward stroke completed at release.....		
75. Proportion of return stroke uncompleted at compression.....		
76. Mean effective pressure (lines 22 and 23)..... lbs.		

CYLINDER RESULTS.

77. Total water consumed per indicated horse-power per hour corrected for moisture in steam..... lbs.

78. Water consumed per I.H.P. per hour by cylinders alone (from line 56)..... lbs.

	H. P. Cyl.	L. P. Cyl.
79. Steam accounted for by indicators at cut-off.... lbs.		
80. Steam accounted for by indicator at release.... lbs.		
81. Proportion of feed-water used by cylinders (line 78) accounted for at cut-off.....		
82. Proportion of feed-water used by cylinders accounted for at release		

DISCUSSION.

Professor Lanza.—I should like to ask the committee two questions: First, whether they considered what should be the minimum duration of the test, in order to keep within proper limits the error in the total water consumption that would arise from the error liable to occur in the reading of the water-glass at the beginning and end of the test.

Second, whether they considered how great would be the difficulties in the way of using two indicators on each cylinder in a road test, instead of one indicator with long pipe connections, and a three-way cock; for we all know that the use of the latter method would not be tolerated in the test of a marine or of a stationary engine, if the test laid claim to being thoroughly performed.

Mr. William Forsyth.—In reply to Professor Lanza as to the possible error in reading the water-glass: The weight of water used by a modern express passenger locomotive on a trip of 150 miles is about 40 tons.

The evaporating surface at middle gauges for a 56-inch boiler with 9 feet Belpaire fire-box is 128 square feet, and the weight of water is about 5 lbs. per square foot for each inch in depth, so that an error of one-fifth of an inch in reading the glass would make a difference of 128 lbs. of water, which is one-sixth of one per cent. of the total water used per trip. The gauge can be read accurately within less than one-fifth of an inch and is liable to be too high as often as too low, and I should say that in an average of a number of trips the possible error due to the inaccurate reading of the glass is not more than one-tenth of one per cent.

Mr. George Gibbs.—It has been my fortune to have had charge of quite extensive series of locomotive tests at various times, and I think I can speak with appreciation of the report of this Committee and the very excellent manner in which they have presented the difficulties of making such tests, both on the road and in the shop, and the questions of vital importance embodied therein. Professor Lanza has spoken of one or two points where he thinks possibly the recommendations of the Committee do not give sufficiently accurate results. I am inclined to think, however, that in both of the cases he mentions, the recommendations are well within the errors of observation. I have myself made experiments on the effect of long and short indicator pipes on road tests, and concluded it absolutely impossible to find any practical difference between the results with pipes located as shown on page 1321 of the report and the plan of placing an indicator close to each end of the cylinder, while the objections to the use of two indicators with very short pipes are almost insurmountable in practice. Regarding the estimation of water used, I have found certain properly calibrated water-meters to give very accurate results, and think the plan of the Committee gives all desired accuracy, when we consider that some other conditions of a road test introduce uncertainties of more importance than the error here could possibly be. Of course, this is only applicable to long-distance tests—say 100-mile runs. I think perhaps it is ungracious to attempt to criticise the excellent report of the Committee, but there is one

point which occurs to me upon hasty reading where I think minor arrangements might be improved upon. For instance, they speak of placing the vacuum gauge glass directly on the smoke arch at the indicator box, out on the front of the engine. Now, my objections to this are that the men have all they can do there in properly taking cards and pyrometer readings, without attempting more, and also that the vacuum gauge readings are vitiated there by excessive fluctuations in level occasioned by sudden exhaustion of a short length of pipe, and more especially by reason of the fireman's opening the furnace door in putting in fuel; this latter will generally reduce the vacuum by 50%. I prefer to have the gauge inside of the cab, where the long pipe connection necessary is an advantage for the above reason.

DLIII.*

THE PERFORMANCE OF A TRIPLE-EXPANSION PUMPING ENGINE WITH AND WITHOUT JACKETS.

BY J. E. DENTON, HOBOKEN, N. J.

(Member of the Society.)

THE engine under notice is the latest design of crank pump of the National Transit Company, for use in pumping oil through pipe lines. It is located at Laketon, Indiana, and has been in use about six months.

After testing the engine, under the conditions recommended by the builders, for best economy, the writer was permitted to determine the water consumption under various special conditions, such as dispensing with the jackets on high cylinder, and on all the cylinders and re-heaters, and operating with as low as 113 lbs. boiler pressure. Table II. summarizes the results of these tests.

The results of these special tests, and the data regarding the efficiency of petroleum as a fuel, the latter being consumed to generate the steam, are believed to be of sufficient interest to be recorded in our *Transactions*.

We will first give a general description of the method of tests, and the duty obtained under the best conditions:

The engine (Figs. 420 and 421) has three horizontal steam cylinders, with the piston-rod of each directly connected to a pair of double-acting plungers working through external packing-boxes. Its dimensions are given in Table I. A connecting-rod from the cross-head of each piston drives a crank on the fly-wheel shaft. The three cranks are set at angles of 120°, the low crank leading. Each cylinder is operated with Corliss valves provided with a convenient arrangement for adjusting the cut-offs by hand. All the steam cylinders are jacketed on their barrels, and partly over their heads. The jackets are cored in the cylinders (Figs. 422, 423, and 424). The intermediate and low

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers, and forming part of Volume XIV. of the *Transactions*.

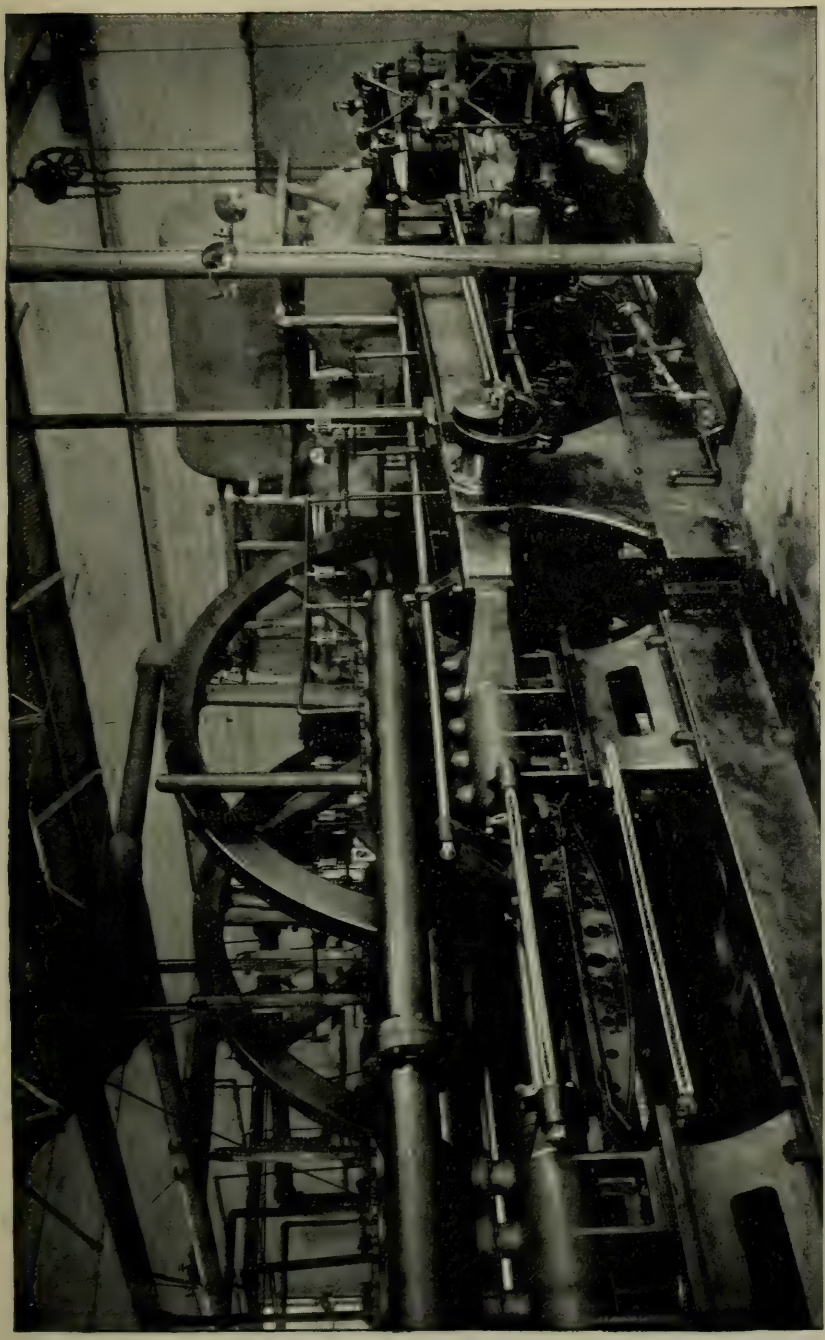


FIG. 420.

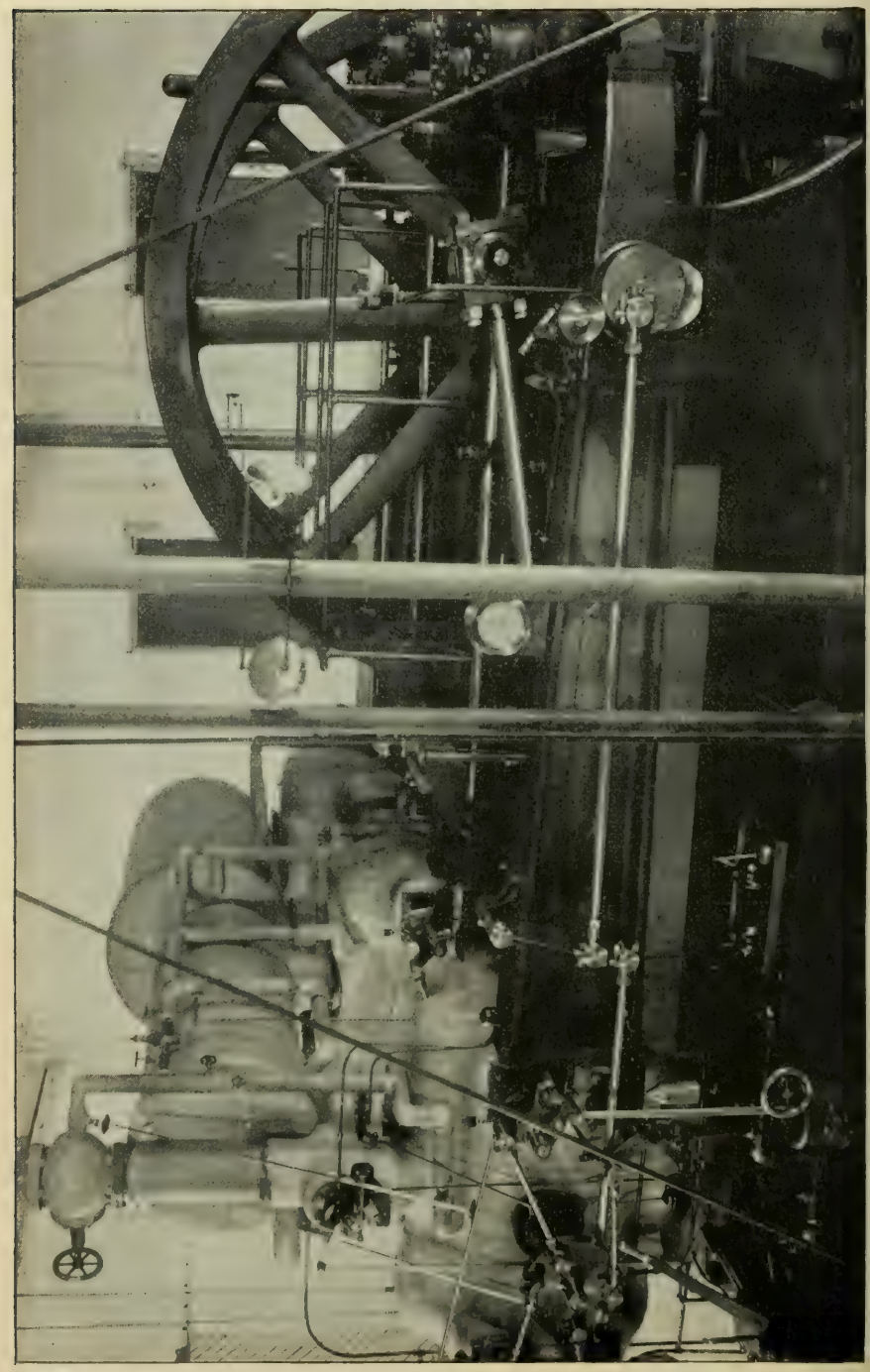


FIG. 421.

receivers are large cylinders, each containing a nest of re-heating tubes, the interior of which are connected with the intermediate and low jackets (Figs. 425 and 426). The cylinders and receivers are well covered with non-conducting plaster. The air pump, boiler feed pump, and pumps for feeding the jacket-water to boilers, are driven from levers worked from the cross-head of the low cylinder.

The engine was tested during the performance of its regular duty, which was the pumping of about 30,000 barrels of petroleum through 54 miles of pipe, under about 600 lbs. pressure per square inch. The only special arrangement for the tests was

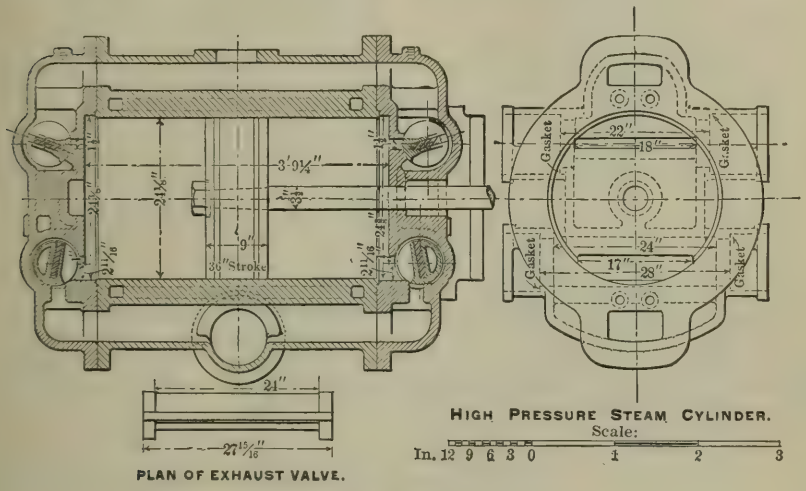


Fig. 422.

the removal of the condensed steam from the jackets and reheaters through Nason traps instead of by the jacket-pump. The Nason traps were located about seven feet below the bottom of the jackets. The water discharged by the traps was cooled by a surface-condenser, and then weighed on scales. The feed-water was weighed in a large tank on a platform scale. The work done by the pump plungers was determined by a newly calibrated Ashcroft pressure gauge, and also by indicator cards taken with a special indicator calibrated by dead weight. Both methods agreed within one fourth of one per cent. The work of the steam cylinders was determined with a set of new Tabor and Thomson indicators carefully calibrated for the occasion.

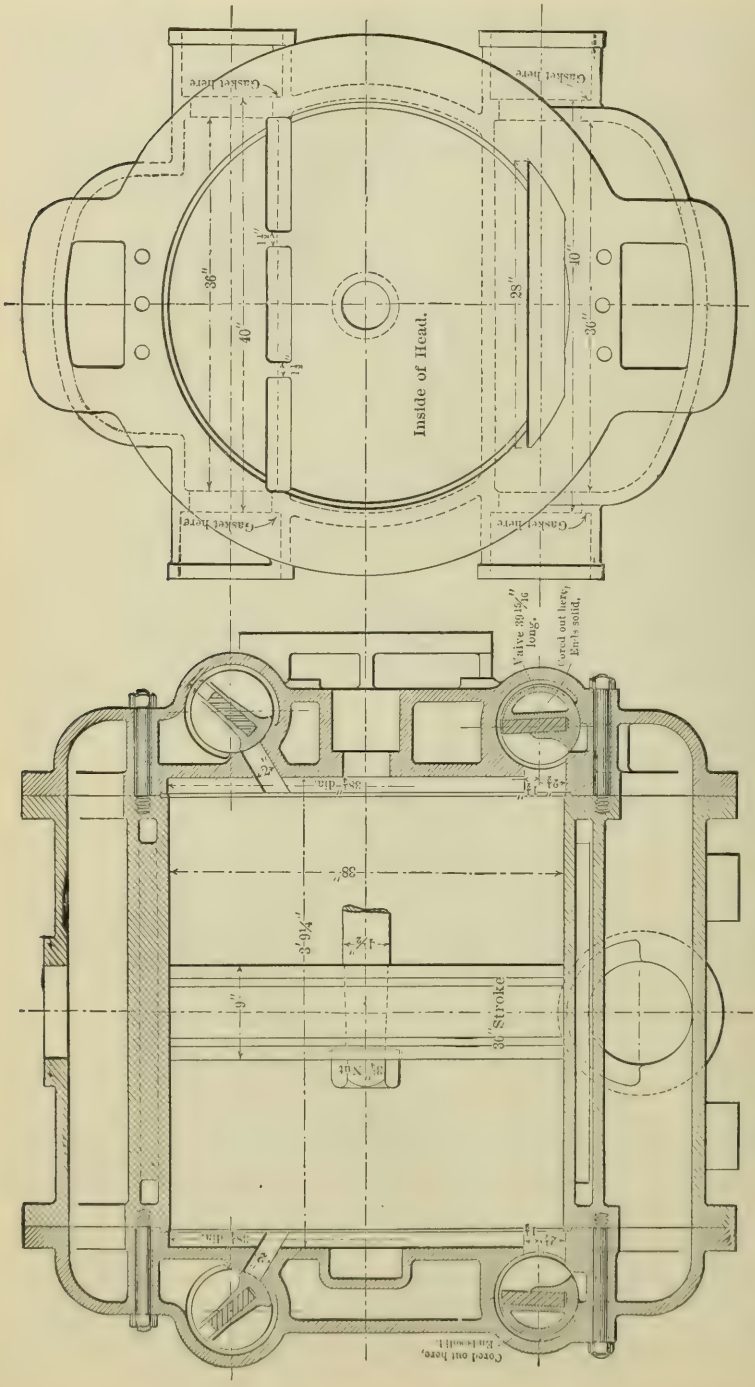

Inside of Head.
Gasket here
Gasket here
Gasket here
Gasket here
36"
40"
28"
10"
36"
Valve 39 15/16" long.
Bored out here, Ends solid.
38"
3'-9¼"
¾"
9"
30" Stroke
Nut
Bored out here, Ends solid.
INTERMEDIATE STEAM CYLINDER.
Scale:
Inches 12 9 6 3 0
1 2 3 Feet
39 15/16"
36"
PLAN OF EXHAUST VALVE.

FIG. 423.

The indicators were cleaned and oiled every hour. Steam was supplied by two horizontal return tubular boilers, 60 inches diameter, 14 feet long, containing 182 two-inch tubes. All pumps and small motors about the station were supplied with steam from a separate boiler. The inlet valves of the high cylinder were tested, and found to permit no leakage of steam into the cylinder after cut-off.

The fuel used was petroleum oil, hence the duty of the

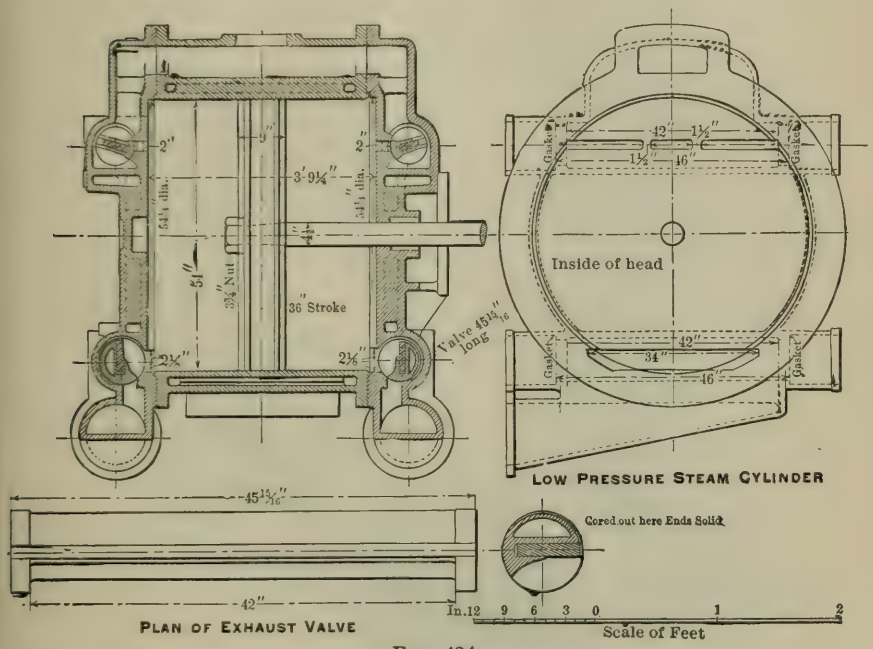


FIG. 424.

engine is stated on the assumption that 10 lbs. of water would be evaporated per pound of coal at the actual boiler pressure, and from the temperature of the feed, which would result from the mixture of the jacket-water and the hot-well water—about 125° Fahr. On this basis the duty per 100 lbs. of coal, under the best conditions of operation, was found to be as follows:

Test of April 2d.	Duty.	134,674,866	foot lbs.
" " " 6th.	"	134,338,841	" "

The moisture in the steam was determined by a superheating calorimeter. The amount of moisture averaged 2.5%, which is

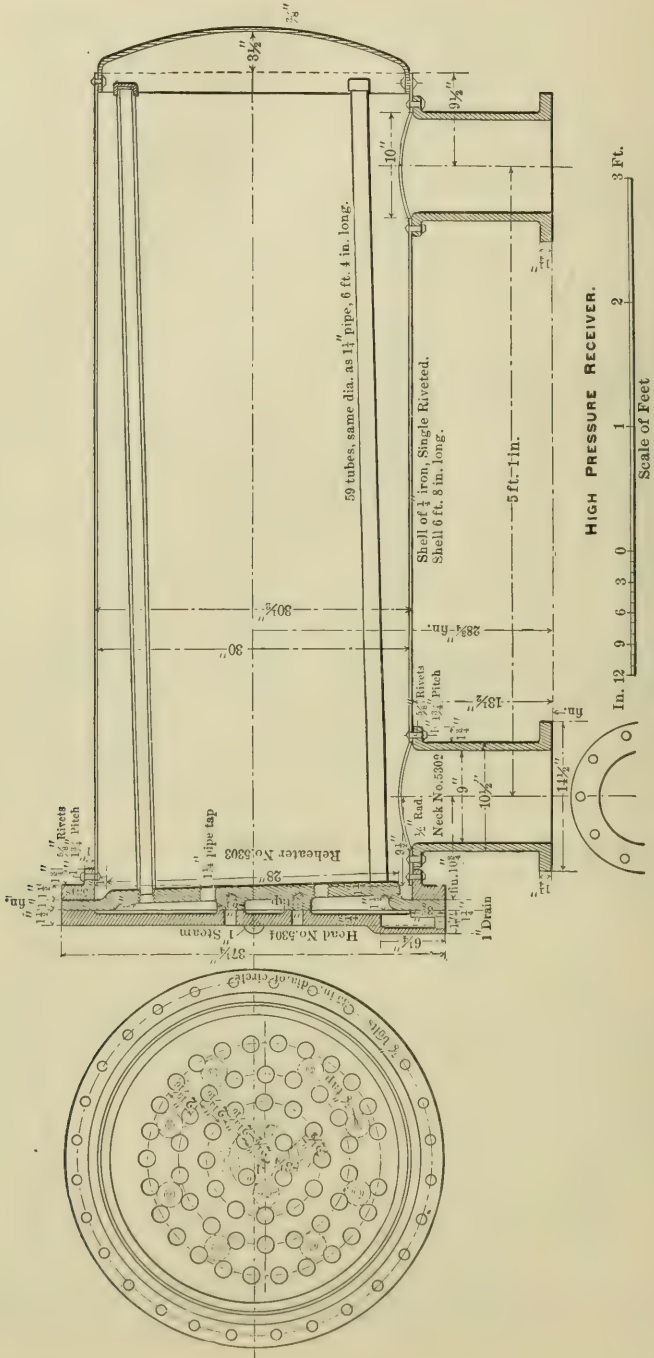

59 tubes, same dia. as 1¼" pipe, 6 ft. 4 in. long.
Shell of ¼ iron, Single Riveted.
Shell 6 ft. 8 in. long.
5 ft. 1 in.
HIGH PRESSURE RECEIVER.
Scale of Feet
In. 12 9 6 3 0 1 2 3 Ft.
Heater No. 5302
Head No. 5301
1" Steam
1" Drain
Neck No. 5300
½ Rad.
Rivets
Pitch
Ctrs. Dias. of Circles

FIG. 425.

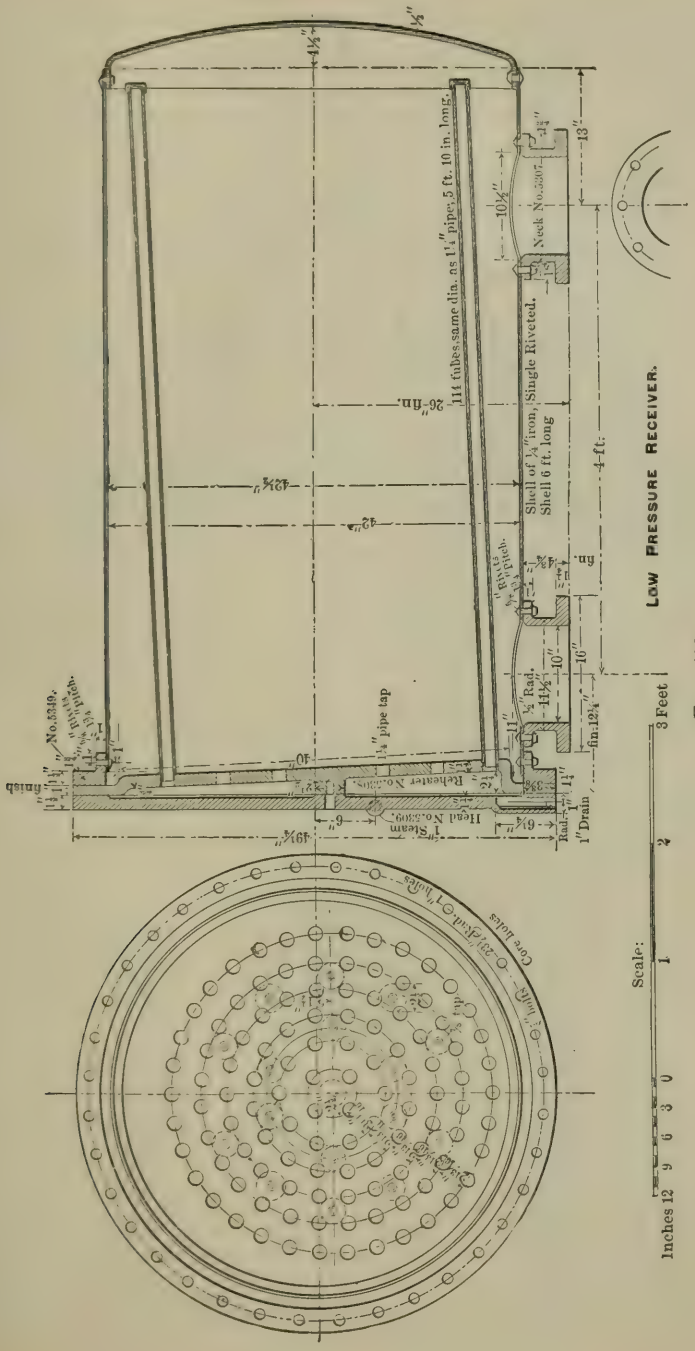

LOW PRESSURE RECEIVER.
Scale:
3 Feet
Inches 12 9 6 3 0
114 tubes, same dia. as 1¼" pipe, 5 ft. 10 in. long.
Shell of ¾" iron, Single Riveted.
Shell 6 ft. long
Neck No. 5307.
26" flu.
42¾"
42"
4 ft.
13"
10½"
Heater No. 5308.
Steam Head No. 5309.
Drain
Core bars
Flanges
Ribs
Bolts
Rad.
Pipe tap
Anchor
No. 5349.

FIG. 426.

accounted for by the condensation in the main steam pipe, the latter being 6 inches diameter, and 100 feet long.

The efficiency of the mechanism was found to average 94.5%.

All valves and stuffing-boxes were packed with metallic packing.

The slip of the pumps was determined to be 0.7% by pumping for three hours from a large calibrated tank.

The consumption of lubricating oil was two-thirds of a gallon of machine oil, and one and three-quarters gallons of cylinder oil per 24 hours.

The mean effective pressures of all the indicator cards, and of the performance of the boiler, are given at the end of the paper in Tables 7 to 14.

The writer is indebted to Messrs. Lufkin, Towl, Cobb, and Church, of the expert engineering corps of the National Transit Company, for skilful assistance and cordial co-operation in carrying out the experiments.

DUTY OF ENGINE.

The trials made under the conditions recommended by the builders for best economy are Numbers 1, 3, and 7, of Table II. They give the following results:

	Duration in hours.	Pounds feed-water per hour per horse-power.	Pounds of dry steam per hour per horse-power.	Friction in per cent. of horse-power.	Moisture in steam at entrance to engine.
March 31. 151 lbs. in high and 67 lbs. in low jackets and re-heaters.....	6	13.71	13.37	7.5	2.5
April 2. 151 " " 43 " " " "	6	13.77	13.43	6.3	2.5
April 6. 151 " " 72 " " " "	5	13.95	13.67	5.4	2.4
Average.....	.....	13.81	13.49	6.4	2.5

Assuming 10 lbs. of water to be evaporated per pound of coal, we, therefore, have

$$\text{Duty per 100 lbs. of coal without correcting for moisture in steam due to radiation from main steam-pipe.} = \frac{(1 - 0.064) \times 1{,}980{,}000}{\frac{13.80}{10}} \times 100 = 134{,}295{,}652 \text{ foot lbs.}$$

$$\text{Duty per 100 lbs. of coal correcting for moisture.} = \frac{(1 - 0.064) \times 1{,}980{,}000}{\frac{13.49}{10}} \times 100 = 137{,}375{,}834 \text{ foot lbs.}$$

Using the heat unit basis recommended by Committee of A. S. M. E. on Pumping Engine Tests, but assuming only dry steam supplied engine, we have

$$\text{Duty* per 1,000,000 British thermal units imparted to steam by boiler, assuming steam perfectly dry on entering engine.} = 124{,}884{,}097 \text{ foot lbs.}$$

* This figure is obtained as follows: The average feed-water per hour for the three trials is 4,448 lbs., and the average jacket-water 775 lbs. per hour. If the steam was perfectly dry, 97.5% of these quantities would have been used, assuming that the 2.5% of water in the steam performed no useful work in passing through the engine. This is not strictly true, as the water would give up heat equal to the difference between the boiler pressure boiling point and its final temperature in the cylinders and jackets. Such heat would represent an evaporation of about seven-tenths per cent. of the total feed-water. We have, therefore, for dry steam at engine,

$(4{,}448 - 775) \times 0.975 = 3{,}581$ lbs. per hour entering cylinders,
and 756 " " " jackets. The jacket-water would return to the boilers at 296° Fahr.,

and the remainder at 91°, the temperature of the hot-well. The mean temperature of feed would, therefore, be $\frac{3{,}581 \times 91 + 775 \times 296}{3{,}581 + 775} = 125°$ Fahr. Each pound of steam evaporated at 151 lbs. pressure would, therefore, require $1.225 - 125 = 1{,}100$ thermal units. Hence, each horse-power would require $1{,}100 \times 13.49 = 14{,}839$ thermal units. Whence, if it is assumed that each pound of coal imparts 10,000 heat units to the water, as per A. S. M. E. Committee's recommendation, the duty per 100 lbs. of coal is

$$\frac{(1 - 0.064) \times 1{,}980{,}000}{\frac{14{,}839}{10{,}000}} \times 100 = 124{,}884{,}097 \text{ foot lbs.}$$

TABLE I.

DIMENSIONS OF ENGINE.

High Cylinder.

Diameter of cylinder	24.125 inches.
Diameter of piston-rod	3.5 inches.
Diameter of pump plungers	6.5 inches.
Stroke *	35.875 inches.
Clearance per cent. of piston displacement :	
Inlet port	0.33
Exhaust port	0.33
Top of exhaust valve	1.26
Piston clearance $\frac{7}{32}''$ =	0.61
Total	2.53
Area inlet port per cent. of piston area	6.0
Area exhaust port per cent. of piston area	12.0

Intermediate Cylinder.

Diameter of cylinder	34.0 inches.
Diameter of piston-rod	4.5 inches.
Diameter of pump plungers	6.5 inches.
Stroke	36.0 inches.
Clearance per cent. of piston displacement :	
Inlet port	0.48
Exhaust port	0.16
Top of exhaust valve	1.12
Piston clearance $\frac{1}{8}''$ =	0.34
Total	2.10
Area inlet port per cent. of piston area	6.0
Area exhaust port per cent. of piston area	8.0

Volume of receiver 3.3 times volume high piston displacement.

Re-heating surface, 59 $1\frac{1}{4}$ tubes $6\frac{1}{3}$ feet long = 137 square feet.

Low Cylinder.

Diameter of cylinder	54.0 inches.
Diameter of piston-rod	4.5 inches.
Diameter of pump plunger	6.5 inches.
Stroke	35.813 inches.
Clearance per cent. of piston displacement :	
Inlet port	0.183
Exhaust port	0.430
Top of exhaust valve	0.820
Piston clearance $\frac{3}{16}''$ =	0.520
Total	1.953

* The length of stroke was cleverly measured by Mr. Towl by clamping the pencil mechanism of an indicator to the crossheads, and thereby recording the travel of the pistons on a fixed plane with which the pencil was brought in contact.

Area inlet port per cent. of piston area..... 3.5
Area exhaust port per cent. of piston area..... 6.1
Volume of receiver 2.4 times piston displacement of intermediate cylinder.
Re-heating surface, 114 1¼ tubes 5.85 feet long = 240 sq. ft.

	High.	Intermediate.	Low.
Piston displacement—cubic feet...	9.42	23.5	47.6
Ratio	1	2.49	5.06

Air pumps, two, single-acting, diameter..... 21.5″ stroke 18″
Feed pumps, two, single-acting, diameter..... 2.5 stroke 12″
Diameter of crank-pins..... 5.5″
Diameter of wrist-pins..... 4.5″
Diameter of fly-wheel shaft bearings..... 10.0
Fly-wheels, two, diameter 13 ft. Weight 12,300 lbs. each.

TABLE II.

RÉSUMÉ OF RESULTS.

		151 lbs. in high jacket; 67 lbs. in Int. and low jackets and re-heaters. 0.47 cut-off in low cylinder.	151 lbs. in high jacket; 135 lbs. in Int. and low jackets and re heaters. 0.47 cut-off in low cylinder.	150 lbs. in high jacket; 43 lbs. in Int. and low jackets and re-heaters. 0.47 cut-off in low cylinder.	113 lbs. in high jacket; 113 lbs. in Int. and low jackets and re-heaters. 0.44 cut-off in low cylinder.	No steam in jackets or re-heaters. 0.45 cut-off in low cylinder.	No steam in high jacket; 75 lbs. in Int. and low. 0.52 cut-off in low cylinder.	151 lbs. in high jacket; 72 lbs. in Int. and low jackets and re-heaters. 0.53 cut-off in low cylinder.	No steam in high jacket; 62 lbs. in Int. and low jackets and re-heaters. 0.4 cut-off in low cylinder.
Number or trial	1	1	2	3	4	5	6	7	8
Date of trial	2	Mar. 31	Apr. 1	Apr. 2	Apr. 4	Apr. 5	Apr. 5 & 6	Apr. 6	Apr. 6
Duration of trial	3	6 hours.	5 hrs.	6 hrs.	8 hrs	3 hrs.	12 hours.	5 hrs	8 hrs.
Revolutions per minute	4	27.33	27.57	27.65	27.83	27.66	27.94	28.3	28.0
PRESSURES.									
Outlet of pump .. lbs. per square inch above atmosphere	5	597	601.5	606	604.5	602.4	602.5	608.4	591
Back pressure on pump plungers .. lbs. per square inch above atmosphere	6	2	2	2	2	2	2	2	2
Net pressure on pump plungers	7	595	599.5	604	602.5	600.4	600.3	608.4	589
Boiler pressure .. lbs. per square inch above atmosphere	8	151	151	150	113	151	151	151	152
Pressure cut-off high cylinder	9	144.5	145.7	146.4	107 4	146.2	146.4	147.7	149
" release " "	10	26.1	28.1	28.0	32.6	38.2	26.4	27.2	26.3
" cut-off Int. "	11	22.7	26.4	21.8	27.0	24.2	22.1	21.6	21.25
" release " "	12	2.0	2.5	2 0	3.6	3.6	2.15	2.0	3.75
" cut-off low "	13	1.7	2.2	1.3	3.5	−3.35	0.67	0.26	4.7
" release " "	14	−6.5	−6.7	−6.6	−6.0	−8.4	−6.26	−6.4	−6.4
" in jacket high cylinder	15	151	151	150	113	0	0	151	0
" " Int. re-heater and jacket	16	67	135	43	113	0	75	72	62
" " low " " "	17	67	135	43	113	0	75	72	62
" " Int. receiver	18	27	31.7	26.8	32.6	30	26.5	26.5	25.5
" " low "	19	2.5	3.2	2.1	4.6	0	1.14	0.6	5.8
Vacuum in inches of mercury	20	26.1	26.1	26.25	26 2	26.1	26.2	26.25	26.2
Barometer " " "	21	28.7	28.8	29.3	29.8	29.1	29.3	29.4	29.1
CUT-OFFS, Per cent. of Stroke.									
High cylinder admission	22	22.8	20.9	23.3	36.1	31	22.6	21.5	21.56
" " release	23	100	100	100	100	100	100	100	100
Int. " admission	24	40.4	41.3	40.1	39.1	39.6	42.7	43.4	42.7
" " release	25	99.8	100	100	100	99.8	99.8	98.0	100
Low " admission	26	46.8	46.8	46.95	44.3	44.6	52	53.2	39.4
" " release	27	99.6	99.5	99.2	99.6	99.8	99.7	99.5	99.4
TEMPERATURES, Fahrenheit.									
Engine room	28	82°	77°	80°	80°	82°	75°	72°	77°
Atmosphere	29	70°	61°	61°	60°	76°	50°	45°	47°
Hot-well	30	90°	89°	92°	92°	95°	90°	90°	90°
Jacket-water	31	300°	356°	280°	336°	...°	310°	308°	299°
Total feed-water per hour in pounds	32	4,351	4,469	4,429	4,617	4,622	4,475	4,563	4,416
" jacket " " " "	33	794	910	669	705	0	767	863	763
Percentage of moisture in steam-pipe entrance to engine	34	2.5	2	2.5	2.25	2	2	2	2.4
Percentage of moisture at boilers	35	0	0	0	0	0	0	0	0
HORSE-POWERS:									
Aggregate of three steam cylinders	36	317.3	322.84	321.67	322.3	328.05	323.27	327.08	313.7
" " six pump plungers	37	293.35	298.17	301.25	302.49	299.59	302.67	309.59	297.52
Friction of mechanism in per cent. of indicated horse-power	38	7.5%	7.6%	6.3%	6.1%	8.7%	6.6%	5.4%	5.1%
ECONOMY OF ENGINE.									
Lbs. of feed-water per hr. per I. H. P.	40	13.71	13.84	13.77	14.33	14.99*	13.84	13.95	14.08
" dry steam " " "	41	13.37	13.56	13.43	14.02	14.69†	13.56	13.67	13.71
MEAN EFFECTIVE PRESSURES.									
High cylinder .. ibs. per square inch	42	51.5	45.3	54.1	43.6	64.4	50.7	52.46	52.3
Int. " " " "	43	12.2	14.5	11.6	13.1	17.9	13.2	13.3	9.0
Low " " " "	44	11.75	12.1	11.4	12.8	7.0	11.3	10.9	12.2
Sum reduced to low cylinder	45	27.97	28 2	27.84	27.90	28.59	27.89	27.85	27.0
‡Heat units per minute per I. H. P.	46	249.7	248.1	252.6	260.2	264.4	252.2	253.4	256.0

* Read 14.09. See foot note, page 1359. † Read 13.79. See foot note, page 1359.
‡ Added since the meeting. See foot note, page 1357.

DISCUSSION OF RESULTS OF THE ENGINE PER ORMANCE.

Table II. gives the data of all of the experiments made, and the water quantities per hour and per horse power.

Table III. gives the distribution of the steam throughout the cylinders, as deduced from the indicator cards, for the Laketon engine and several other well-known engines whose steam economy has been experimentally determined by satisfactory tests. It should be noted that, in Table III., the jacket-water and cylinder condensation have been expressed in per cent. of the *water entering the high cylinder*, instead of in terms of the total feed-water, as is the usual custom. This has been done for convenience in applying a certain method of exhibiting the various causes of loss of theoretical economy, which will be explained later on. From the contents of these tables the following deductions are made :

I.

TESTS AT 151 LBS. BOILER PRESSURE WITH JACKETS.

If we regard the measurements of indicated horse-power and water as liable to an error of one per cent., which is probably a minimum allowance for the most careful determinations, the steam economy is the same for the following conditions :

(*a*) Any pressure from 43 to 131 in the intermediate and low jackets and receivers.

(*b*) Any pressure from 0 to 151 in the jacket of high cylinder.

(*c*) Any cut-off from 21 to 23 per cent. in high cylinder.

Any cut-off from 39 to 43 per cent. in intermediate cylinder.

Any cut-off from 40 to 53 per cent. in low cylinder.

TABLE III.

FEED-WATER PER STROKE. [NO DEDUCTION FOR MOISTURE IN STEAM.]

		Test No. 1.		Test No. 2.		Test No. 3.		Test No. 4.		Test No. 5.		Test No. 6.		Test No. 7.		Test No. 8.		Steamship *Iona*. Triple.		Steamship *Metcor*. Triple.		Sulzer Corliss. Triple.		Wheelock, Corliss, Rockwood & Green Tests.			
		151 lbs. in high jacket; 67 lbs in int. and low jackets and reheaters; 0.47 cut-off in low cyl.		151 lbs. in high jacket; 135 lbs in int. and low jackets and reheaters; 0.47 cut-off in low cyl.		159 lbs. in high jacket; 43 lbs. in int and low jackets and reheaters; 0.47 cut-off in low cyl.		113 lbs. in high jacket; 113 lbs. in int. and low jackets and reheaters; 0.44 cut-off in low cyl.		No steam in jackets or reheaters; 0.45 cut-off in low cyl.		No steam in high jacket; 75 lbs. in int. and low; 0.52 cut-off in low cyl.		151 lbs. in high jacket; 72 lbs. in int. and low jackets and reheaters; 0.53 cut-off in low cyl.		No steam in high jackets; 62 lbs. in int and low jackets and reheaters; 0.4 cut-off in low cyl.						Triple.		Compound.	
		Lbs	Per cent	Lbs.	Per cent.	Lbs.	Per cent.	Lbs	Per cent.	Lbs.	Per cent.	Lbs.	Per cent.	Lbs.	Per cent	Lbs.	Per cent.	Lbs.	Per cent.	Lbs.	Per cent.	Lbs.	Per cent.	Lbs.	Per cent.	Lbs.	Per cent.
Fed to boilers	1	1.33	118.9	1 35	125 5	1 273	118.7	1.382	117.9	1.390	100.0	1.73	120.0	1.343	123.0	1.310	121 0	1.175	105.9	3 48	110 93	1.117	117.21	0 272	119.7	0 249	116.35
Condensed in all jackets and reheaters	2	0.212	18 9	0.275	25.5	0 201	18.7	0.210	17 9	None.	.....	0 23	20.9	0.254	23 3	0 229	21.1	0 058	5.19	0.34	10 8	0.164	17 2	0 044	19.7	0 35	16.35
Admitted to high cylinder	3	1.118	100.0	1 075	100.0	1.072	100 0	1.172	100 0	1.390	100.0	1.10	100.0	1.089	100 0	1.081	100 0	1.17	100 0	3.14	100 0	0.953	100.00	0 228	100.	0 214	100.
Accounted for at cut-off high cylinder exclusive of clearance	4	0 825	73.8	0.768	71.4	0.867	80.8	0.983	83.8	1.103	79 2	0.798	72 5	0.797	73.1	0.807	74 6	0.831	74 3	2.607	83 0	0 819	86.0	0.173	75.4	0.155	72 4
Condensed during admission to high cylinder	5	0 293	26.2	0.307	28.6	0.205	19.2	0.189	16.2	0.289	21.8	0.302	27.5	0.292	26.9	0.274	25.4	0.286	25.7	0 533	17.0	0 100	14.0	0.055	24.6	0 059	27.6
Re-evaporated or collapsed during expansion in high cylinder	6	0.095	8 4	0 191	18 0	0 096	8 95	0 082	6 99	0.087	6 25	0 136	12.3	0.154	14.1	0.103	9.5	—0.009	—8.0	—0.083	2.64	0 103	10 80	0.011	4 82	0.012	5 61
Exhausted from high cylinder	7	0.919	82.2	0 962	89.4	0.963	89.8	0 965	82.3	1 190	85.4	0.943	86.0	0.951	87.3	0.909	84.0	0.823	73 6	2 524	80.3	0 924	96 96	0.184	80.7	0.167	78.03
Accounted for at cut-off intermed. cylinder exclusive of clearance	8	0 868	77.6	0.982	91.3	0 857	79 9	0.943	80.4	0.898	64 5	0 909	82.6	0.920	84.4	0.894	82 7	0.873	78.1	2.78	88.5	0 979	102 7	0.210	92 1	.....	.....
Re-evaporation or collapsed during expansion in intermed. cylin.	9	0 158	14.1	0.018	1.67	0.132	12 3	0.176	11.6	0.068	4 8	0.088	8.0	0.049	4.49	0.187	17.2	0.005	4.47	—0.066	—2 1	0 013	1.36	0.02	8.77	.....	.....
Exhausted from intermediate cylinder	10	1.026	91.7	0 100	9.20	0 988	92.1	1.079	92 0	1.065	76.5	0.957	90.0	0.969	88.9	1.080	99.0	0.879	78.6	2.714	86 4	0.992	104.09	0 230	100.88	.....	.....
Accounted for at cut-off in low cylinder exclusive of clearance	11	0 922	82 4	0 950	88 3	0 919	85.7	0.998	85.1	0.621	44.6	0 977	88.8	0 974	89.4	0.929	85 9	0.661	59.1	2.471	78.6	0.918	96.32	0.182	79.8	0.186	86.9
Re-evaporated or collapsed during expansion in low cylinder	12	0.043	3.84	—0.01	.....	0.066	6.15	0 093	7 93	0.120	8.62	0.053	4 8	0.047	4 31	0.069	6.37	— 0 005	—4.47	—0.065	—2 7	0.118	12.38	—0.011	—4.82	—.016	—7.48
Accounted for at release of low cylinder exclusive of clearance	13	0 965	86.3	0.940	87.4	0.985	91 8	1 091	93.0	0.741	53 2	1.030	93.6	1.021	93 7	0 998	92.3	0.656	58.7	2.406	76.6	1 036	108.7	0.171	75.0	0.17	79.4
Total re-evaporation or collapse between cut-off in high cylinder and release in low cylinder	14	0.140	12 5	0.172	16.0	0.118	11.0	0 908	9.21	—0.362	—26.0	0.232	21.0	0.224	20.5	0.191	17.6	—0.176	—15.7	—0.201	—6.66	0.182	19.2	0.002	0.88	0.015	7.01
		RANGE OF TEMPERATURE [FAHRENHEIT] IN CYLINDERS.																									
High cylinder	15	90 deg.		86 deg.		92 deg.		80 deg.		80 deg.		90 deg.		91 deg.		95 deg.		86 deg.		77 deg.		92 deg.		72 deg.		130 deg.	
Int. "	16	43 "		49 "		41 "		42 "		61 "		44 "		32 "		31 "		68 "		53 "		31 "		48 "		.....	
Low "	17	81 "		80 "		94 "		84 "		80 "		78 "		78 "		86 "		76 "		91 "		96 "		96 "		87 deg.	

For example, if in test No. 2 we ascribe the high speed and M. E. P. of No. 2, with about two per cent. shorter cut-off in the high cylinder, to the 116 lbs. more steam given to the system by the jackets, we may argue that the lower economy of No. 2 is due to the possibility that the extra 116 lbs. of jacket steam was unable to increase the M. E. P. in the same proportion that it increased the water consumption per horse-power. Or, we may maintain that if the one per cent. of possible error was eliminated by repeated trials, the economy of No. 2 would be equal; or, with opposite errors, better than that of No. 1.

Again, in tests 6 and 8 the conditions were practically identical, but the accidental errors of the power and water measurements have probably affected the tests in opposite directions, and the resulting economy figures therefore differ two per cent. from each other.

If we average tests 6 and 7, the water per horse-power is 13.96, or the same as that of test 7. Yet there is a saving of 100 lbs. of jacket water per hour by dispensing with the jacket on the high cylinder. If we compare the cylinder condensation and re-evaporative actions in the several cylinders, in Table II. we find no evidence of any effect which should neutralize the 100 lbs. saved by non-use of the high jackets. Furthermore, two auxiliary tests, without the use of the high jacket, not detailed herein, indicate that the best economy is obtainable without this jacket in service.

It is therefore probable that the equality of the economy of the average of 6 and 8 with 7 is due to the horse power of 7 being too large by at least the effect of the limit of accidental error. We may therefore conclude that at 150 lbs. boiler pressure, and about 20 expansions, with any pressure above 43 lbs. in all of the jackets and re-heaters, or with no pressure in the high jacket, the performance was as follows:

With 2.5% of moisture in the steam entering the engine, the jackets used 16% of the total feed-water. About 20% of the lat-

* In view of the error in the water per horse-power in Test No. 5 (see foot note, page 1359), the figures in Table III. for this test should be corrected at lines 4, 5, 7, and 14, to read as follows:

No. of line.	Pounds.	Per cent.
4	1.169	84.0
5	0.221	16.0
7	1.256	90.4
14	0.428	30.8

ter was condensed during admission to the high cylinder, and about 13.85 lbs. of feed-water was consumed per hour per indicated horse power.

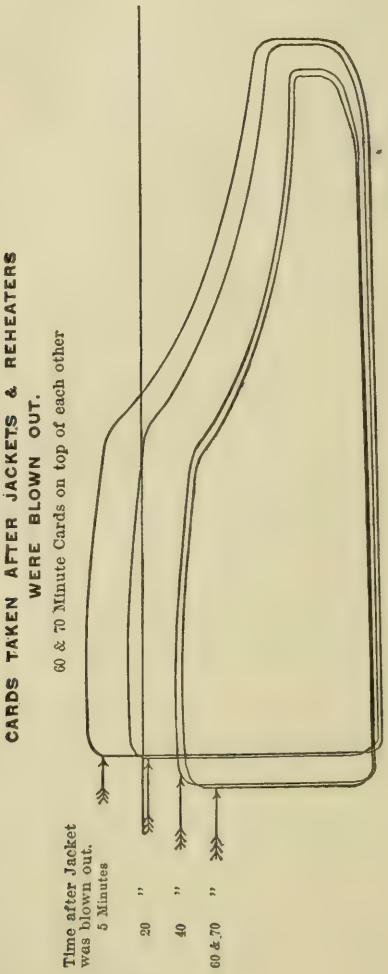


FIG. 427.
CARDS TAKEN AFTER JACKETS & REHEATERS WERE BLOWN OUT.
60 & 70 Minute Cards on top of each other

II.

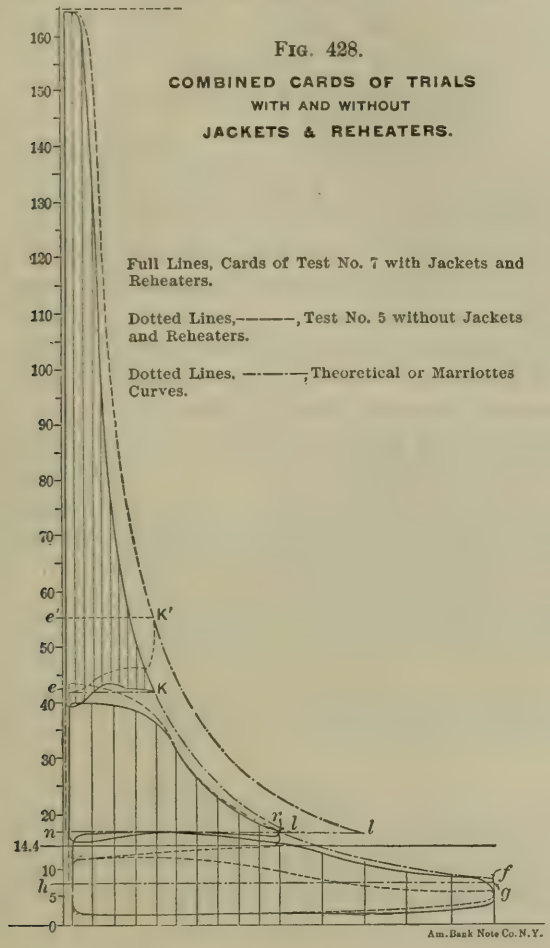
TEST AT 151 LBS. BOILER PRESSURE WITHOUT JACKETS AND REHEATERS.

To prepare for this test, the jackets were blown out by opening the Nason traps to the atmosphere. The speed of the

engine immediately commenced to decrease, and the cut off in the high cylinder was accordingly lengthened, by hand adjustment, to maintain the normal revolutions. This continued for seventy minutes, when the card of the low cylinder ceased to change, as per Fig. 427, and the steam distribution was as per the

FIG. 428.

COMBINED CARDS OF TRIALS
WITH AND WITHOUT
JACKETS & REHEATERS.



combined cards Fig. 428, the cut-off in the high cylinder having been changed during the interval from about 20 to 31 per cent. of the stroke. These conditions steadily maintained themselves, but an additional interval of fifty minutes was allowed for the jackets to cool off before commencing the test. Test No. 5 of Tables

II. and III. shows the results. The water consumption per hour was 14.99 * lbs. per horse power, or 8.3 % † more than that found with jackets and re-heaters in action.‡ By the method of analysis to be explained below, it appears that not more than 6.8 § units of this 8.3 % can be ascribed to the fact that the ratio of expansion available in test No. 5 was 15 as compared to 20.5 in the tests with jackets. The remainder, or 1.5 %, is due partly to losses of pressure due to steam condensed in entering the intermediate and low cylinders, and partly to less perfect exhaust action from the low cylinder in No. 5. There was less per cent. of cylinder condensation to the high cylinder than with the jackets in action, and the re-evaporation during expansion in all the cylinders was as great as in most of the jacket tests; but the collapse of steam in passing from the high to the intermediate, and from the high to the low, was 26 % (line 14, Table III.), against a re-evaporation of upwards 15 % with the jackets. The effect of this collapse is represented in Fig. 428 by comparing the areas e, k, l, n, and e', k', l', n, with the actual areas of the cards between the levels k to l, and the area l, f, g, h, with the actual areas between the levels l and g. The areas e, k, l, n, e', k, l', n, and l, f, g, h, represent the work which the volumes of steam, e', k', e, k, and n, l, exhausted from the intermediate and low cylinders, respectively, might supply with no losses of pressure by drop between the point of exhaust in one cylinder and release in the next. The cards with jackets realize about 87 % of these theoretical areas, and those without jackets about 67 %.

Comparing the several steps involved in the operation with and without jackets, we have the following distribution of effects:

(*a*) If the steam accounted for at cut-off in the high cylinder —that is, the steam present less the amount compressed in the clearance space, expanded according to a Mariotte curve with no losses by "drop" between cylinders, and with a perfect ex-

* Read 14.09. See correction, Table II. † Read 1.9.

‡ *Added since the meeting.*—The *fuel* consumption would, however, be proportional to the heat units per horse-power. Hence, if the condensed steam from the jackets is returned to the boiler by mixing with the feed-water, the *fuel* per horse-power would be 5.2% greater without jackets than with the latter in use.

§ *Added since the meeting.*—Read, "It appears that 6.8% can theoretically be ascribed to the fact that the ratio of expansion available in Test 5 was 15, as compared to 20.5 in the tests with jackets." See foot note, page 1359.

haust against two pounds absolute back pressure (see dotted diagram, *a*, *b*, *f*, *g*, *h*, Figs. 429 to 435)—the water per hour per horse-power would be:

For 20.5 expansions used with jackets, 8.13 lbs.; for 15.0 expansions used without jackets, 8.75 lbs.

The aggregate M. E. P. of the three cylinders is 94 % of the theoretical with jackets, and 74 % without jackets. Hence by the losses by "drop" of pressure the water per horse-power becomes $\frac{8.18}{0.92} = 8.85$ lbs. with jackets, and $\frac{8.75}{0.74} = 11.82$ lbs. without jackets. These amounts are each 79 % of the water entering the cylinders, the cylinder condensation during admission being 21 % for the average of tests with high jacket and 21 % without. (Line 5, Table III.) Hence the water entering the high cylinder becomes with jackets $\frac{8.65}{0.79} = 11.25$ lbs. per hour per horse-power, and without jackets $\frac{11.82}{0.79} = 14.99^*$ lbs. per hour per horse-power, as found by the experiments.

We must now increase the water expense for the jackets 23 %, making the amount per hour per horse-power $11.25 \times 1.23 = 13.84$, as found by average of experiments 1, 2, 3, and 7.

The difference of theoretical water, or $8.74 - 8.18 = 0.56$, due to the greater ratio of expansion used with the jackets, accounts for $\frac{0.56}{0.79 \times 0.74} = 0.96$ lbs. of the water found by experiment.

We have finally, therefore, gain in economy by use of jackets, $\frac{(14.99 - 0.96 - 13.83)}{13.83} = 1.5$ %; and, gain by greater range of expansion with jackets, $\frac{0.94}{13.83} = 6.8$ %.

It is not to be concluded from these figures that if 20.5 expansions had been used without jackets, the water per horse-power would have been but 1.5 % more without jackets than with the latter in use. The assignment of 6.8 % of the loss to

---

* In view of the fact that the water consumption per horse-power without jackets should have been taken at 14.9 lbs. [see correction Table II], the actual gain of water consumption by jackets was $14.09 - 13.83 = 0.26$. Hence the above analysis leads to the conclusion that the gain due to increasing the ratio of expansion from 15 to 20.5 without jackets, is 4.5% more than the actual gain by the use of jackets.

the principle of expansion is to be regarded only as hypothetical, in order to enable the various classes of loss of effect to be clearly apprehended. If the ratio of theoretical to actual M. E. P. given above at 74 % remained for no jackets the same at all expansions, the figures would hold true practically. It is probable, however, that if 20.5 expansions had been tried without jackets, the *actual weight* of steam collapsed on entering the intermediate and low cylinders would be greater than occurred for 15 expansions. The *per cent.* of loss of theoretical M. E. P. would then be much greater than that, as found in Test 5. I do not doubt, therefore, that the loss of economy by dispensing with the jackets at 20.5 expansions would be greater than the 8.3 % here reported. No experiment at 20.5 expansions without jackets could be made, as the slower speed necessary would have interfered with the required delivery of oil by the pumps.

III.

TEST AT 113 LBS. BOILER PRESSURE WITH JACKETS AND REHEATERS.

The water consumption for this trial (No. 4, Tables II. and III.) is 14.33 lbs. per hour per horse-power, or 3.6% more than at 151 lbs. boiler pressure. In order to maintain the pump at normal speed, the cut-off in high cylinder had to be 36% of the stroke, making the ratio of available expansions by volume 13.5. The theoretical water per hour per horse-power for the steam accounted for at cut-off of high cylinder, *ab*, Fig. 10, if there was no drop between cylinders, would be 9.2 lbs. Had all losses been equal, the percentage of gain for the higher boiler pressure should therefore have been

$$\frac{9.2-8.18}{8.18}=13\%$$

The combined areas of the cards show 90% of the theoretical area *a*, *b*, *f*, *g*, *h*, as compared to 92% at the higher boiler pressure. (Line 5, Table IV.) The cylinder condensation during admission to high cylinder is, however, only 16.1%, and the jacket water only 18% of the water entering this cylinder as compared to 22 and 23%, respectively, for the higher boiler pressure, and these gains reduce the theoretical advantage of the higher ratio of expansion so as to make the actual water consumption only 3.6% greater for the low-pressure.

IV.

COMPARISON OF THE WATER CONSUMPTION PER HORSE-POWER OF THE LAKETON ENGINE WITH THAT OF THE BEST TRIPLE-EXPANSION PRECEDENTS.

We adopt the following method of analysis of the efficiency of the action of the steam as shown by the cards, referring to the combined cards, Fig. 11.

Select a point, y', near cut-off in the high cylinder. Then $x'y'$ represent the volume of steam present at cut-off at pressure ox'. For such differences of pressure as ox' to oz, the density of steam is inversely as the absolute pressure within the limit of error of scaling cards. Hence, if zb be made equal to $x'y' \times \frac{ox'}{ox}$, it will represent the same weight of steam as $x'y'$. Let compression occur to any pressure oz', before admission commences. Then the fraction of clearance space ax to be filled with steam of boiler-pressure when admission occurs is $1-\frac{oz'}{oz}$. Lay off $ax = [1-\frac{oz'}{oz}]\, zx$. Then ab represents the weight of steam, which expanded according to Mariotte's law, would equal the weight accounted for by the indicator cards at cut-off in the high cylinder. Draw bcf as a Mariotte curve, f being distant from o, equal to sy, the length of the low card. Draw hg at two lbs. above the zero line oq. Draw fg and hx parallel to oz. Then if there was no "drop" of pressure by wire-drawing, and no "drop" by cylinder condensation or clearance, between the intermediate and low cylinders, and a perfect exhaust against two pounds' pressure, the work obtained from the weight of steam represented by ab would be represented by the area $abfgh$, and the expansion by volume would be $\frac{\text{Volume of low cylinder}}{\text{Volume } ab}$, or $\frac{sq}{ab}$ = ratio of possible expansion, with compression to oz' in high cylinder. If now we compare the actual aggregate area of the cards with $abfgh$, we have a measure of the degree to which the engine has realized the object of its design, viz.: to obtain the greatest possible effect by expanding steam of pressure oz a number of times equal to $\frac{sq}{ab}$. If there is wire-drawing during

admission, there is a triangular loss of area, or a mean effective pressure $y'ba$, and some of the moisture in the steam, due to priming and cylinder condensation, is evaporated * to the extent of the difference of the total heat of the steam at the pressures oz and ox' respectively. Any such evaporation is credited to the engine by our measurement of the volume or weight of steam present at y', and the difference between this weight and the feed-water, of course, gives the high cylinder and jacket condensation. The proportion of the feed-water devoted to the jackets being determined by proper measurement, we can now analyze the water consumption as follows:

Let the feed-water,† entering the high cylinder, per stroke be 100%.

Let the total feed-water be $100 + s\%$, and the water accounted for at y' be $100 - s'\%$.

Then the cylinder condensation during admission to high cylinder will be $s'\%$.

Let the aggregate mean effective pressure of the actual cards divided by the theoretical or Mariotte mean effective pressure, a, b, f, g, h, be F.

Let the water per hour per horse-power calculated ‡ for a, b, f, g, h, be W.

* The loss of M. E. P. due to wire drawing is much greater than the gain due to the accompanying evaporation of moisture. For example, in Fig. 430, the loss of area, y', b, a, is about 4 % of the M. E. P., while the evaporation of moisture by wire-drawing can be only six-tenths per cent.

† By feed-water we here mean the water fed to boilers, less any leakage or drip water taken by steam before it enters the engine.

‡ The theoretical figures have been calculated, as illustrated below; the numerical calculations giving more accurate results than the planimetering of the diagrams as drawn.

TABLE V.

Table of Theoretical Water Consumption for a perfect Mariotte expansion at 150 lbs. above atmosphere, and 2 lbs. absolute back pressure.

Ratio of expansion. r.	M. E. P. lbs. per square inch. pm.	Lbs. of water per hour per horse-power. W.
10	52.4	9.68
15	38.7	8.74
20	30.9	8.20
25	25.9	7.84
30	22.2	7.63
35	19.5	7.45

Then, as compared to the theoretically possible water consumption with $\frac{sq}{ab}$ expansions from a boiler pressure oz, against 2 lbs. back pressure, we have:

$$Pm = 165\left(\frac{1+\log.\ e,\ x,\ r}{r}\right)-2.$$

$$W = \frac{13{,}750 \times \text{weight of steam per cubit foot at 150 lbs.}}{r}$$

(*a*) The pounds of water per hour per horse-power lost by imperfect cushioning, wire-drawing in all three cylinders, and by cylinder condensation in all cylinders except the high, is

$$\frac{W}{F} - W = W'.$$

(*b*) The pounds of water per hour per horse-power condensed during admission is

$$\frac{W}{F\times(100-S')} - W - W' = W''.$$

(*c*) The pounds of water per hour per horse-power consumed by the use of jackets is $\frac{W\times(100+S)}{F\times(100-S')} - W - W' - W'' = W_3$.

$\frac{W(100+S)}{F(100-S')} = W_4$, is, of course, the water determined by experiment. This method of analysis does not, therefore, impose any theoretical or ideal performance or efficiency. It simply shows how much of the actual water consumption is chargeable to the more or less perfect utilization of the number of expansions with which the engine was designed to work, and how much to cylinder condensation and steam jacket expenditure. We may, of course, determine the loss of area in each cylinder. In most engines the high card area to the point of release, as b, y', k, e, x, equals or exceeds the Mariotte area p, a, b, c, but the "drop" between the intermediate and low cylinders makes the aggregate area a fraction of a, b, f, g, h, as a rule. A notable exception is the Lawrence Compound Pumping Engine (Fig. 432), for which $F = 1.03$, or the actual areas exceed the Mariotte a, b, f, g, h, by 3%. The steam distribution in this engine is, I believe, the most perfect in history, although the economy, 16.48 lbs. of

water per hour per horse-power, is not comparable with the triple-expansion types. The cause of the high value of F in this engine is the great degree of re-evaporation in the high cylinder* during expansion, and its slow speed of 13.6 revolutions per minute, although the clearance is very small, and the cushioning very complete, so that the "drop" is a minimum.

The cylinder condensation during admission is 40% of the steam admitted to the cylinders; that is, of the total feed less the jacket water.

For comparison with the Laketon results, we select the following tests of triple-expansion engines:

1st. Test of engines of S. S. *Meteor* by the Marine Trial Committee of the British Mechanical Engineers. (Fig. 433.) In this engine the ratio of possible expansion was 14 from 147.5 lbs. boiler pressure. The barrels of all cylinders were jacketed with live steam, the pressures in the jackets being high, 132 lbs.; intermediate, 77 lbs.; low, 16 lbs. The cylinders were 29″ × 44″ × 70″ × 48″ stroke, revolutions 72, cylinders connected to three cranks at 120°. The results of the analysis are given in Table IV., whence we have $F = 77\%$, $100 + S = 110\%$, $100 - S' = 83\%$. The jacket-water was not separated from the total feed in the experiment. We have, therefore, assumed it at 10%.

Comparing with the 13.5 expansions of Laketon test No. 4 we find that by the expansion principle the *Meteor* should use 8.82 lbs. per horse-power, and the Laketon 9.2 lbs.

By comparison of values of F, the *Meteor's* advantage due expansion is lost, as we have the values of $\frac{W}{F} = \frac{8.82}{0.77} = 11.3$ lbs for the *Meteor*, and $\frac{9.2}{0.9} = 10.21$ lbs. for Laketon.

*The distribution after release in the high cylinder falls slightly short of that of perfect Mariotte expansion. Thus the volume e, k is exhausted from the high, and should produce the work e, k, l, m, n between the pressures of release k and l. The actual card areas between these levels do not, however, quite equal e, k, l, m, n, so that the excess of the whole action over the Mariotte is due to the high cylinder.

TABLE IV.

DISTRIBUTION OF LOSSES IN VARIOUS MULTIPLE-EXPANSION ENGINES.

		Symbols.	Laketon.			Steamship *Meteor*.	Steamship *Iona*.	Sulzer engine.	Wolff compound Lawrence pump.	Wheelock.	
			Average tests Nos. 1, 2, 3, 6, and 7.	No. 5. No jackets.	No. 4. 113 lbs. boiler pressure.					Compound.	Triple.
Boiler pressure, above atmosphere	1	.....	151	151	113	148	165	143	106	145	140
Revolutions per minute.	2	.....	27.96	27.66	27.83	72.0	61.1	66.4	13.62	79.0	79.0
Ratio of possible expansion by volume from boiler pressure	3	.....	20.5	15.0	13.5	14.0	26.5	24.0	23.5	30.8	28.2
Ratio of actual M.E.P. to theoretical.	4	F.	0.92	0.74	0.90	0.77	0.84	0.85	1.03	0.94	0.95
Theoretical lbs. of water per hour per H.P.	5	W.	8.18	8.74	9.2	8.82	7.8	7.95	8.32	7.6	7.79
Actual lbs. of water per hour per H.P. by experiment	6	W_4.	13.83	14.99*	14.33	14.98	13.35	12.73	16.48	13.11	13.01
Fed to boiler.	7	100 + S.	123%	100%	118%	110%	106%	117%	118%	116.35%	119.7%
Condensed in jackets	8	S.	23%	none	18%	10%	5.29%	17.5%	18%	16.35%	19.7%
Entering high cylinder	9	.....	100%	100%	100%	100%	100%	100%	100%	100%	100%
Accounted for at cut-off.	10	100 − S.	78%	79%†	84%	83%	74%	86%	60%	72.4%	76%

* Read 14.09. See correction, Table II. † Read 82%.

The *Meteor* has less cylinder condensation in the high cylinder (Line 9, Table IV.), and less jacket expense than Laketon, as should be the case on account of the shorter cut-off, and lower speed (Table III.) of rotation. Thus we have for the *Meteor:*

$$\frac{W}{F(100\text{-}S)} = \frac{11.3}{0.83} = 11.30, \text{ and } W_4 = 11.3 \times 1.10 = 14.98 \text{ lbs.};$$

and for Laketon

$$\frac{W}{F(100\text{-}S')} = \frac{10.21}{0.84} = 12.14, \text{ and } W_4 = 12.14 \times 1.18 = 14.30 \text{ lbs.}$$

Hence it is evident that the Laketon engine's superior economy is due wholly to the values of F, or the less loss of area by wire drawing and "drop."

2d. The test of the engines of the S. S. *Iona* (Fig. 430), also by the British Marine Committee. The cylinders were 21.88″ × 34.02″ × 56.95″ diameter × 39″ stroke, revolutions 61.1, connected to three cranks at 120°. The only jacketing was on the barrels of the high cylinder. The ratio of possible expansion was 25.2 from 165 lbs. boiler pressure. The cylinders are nearly the same size as those of the Laketon engine.

Applying the analysis, we have, Table IV.:

$$W = 7.8\,;\ F = 0.84\,;\ 100 + S' = 106\%\,;\ 100 - S' = 74\%.$$

Comparing with the Laketon tests, with jackets and re-heaters at 151 lbs. boiler pressure, we see that the greater expansion in the *Iona* gives 4% less water consumption than the Laketon. $\frac{8.18 - 7.8}{8.18} = 4.6\%$. The values of F, and for cylinder condensation in the high cylinder in favor of Laketon, balance against the jacket expense, which is in favor of the *Iona*. The final result, therefore, favors the *Iona* to just about the same extent as the values of W. It is inconsistent with the influence of speed on cylinder condensation, that the higher rotations per minute of the *Iona* should permit more cylinder condensation in its high cylinder than occurred in the Laketon engine. The range of temperature (Table III.) is also higher in the Laketon high cylinder.

Should the *Iona's* water consumption be corrected for the difference between the 6 and 1.28% of water supplied to hot well to maintain boiler water levels, found respectively on the official and on the sea trial, by the chief engineer, the per cent. of water accounted for at cut-off in high cylinder (Line 9, Table

IV.) would be 78%, and the water per hour per horse power, 12.73 lbs. This figure is quite reasonable in view of the results on the Sulzer engine, as the values of F will be seen to be practically the same in the two engines, and the lower cylinder condensation in the high cylinder of the Sulzer is offset in the *Iona* by the less jacket-water expense.

3d. The tests of the Sulzer engine, a Corliss poppet-valve engine, built at Augsburg, Germany, have been made with care and skill by Professor Schroter* of Munich. In view of the fact that four separate tests on different days closely agree in their results, the record of this engine, with a water consumption of 12.73 lbs. per hour per English horse power, is most satisfactory. The cards are given in Fig 435.

The engine developed 707 English horse-power. Its cylinders are 19.75″ × 29.6″ × 47.25″ × 55.2″ stroke, revolutions 66.4 per minute. The high and intermediate cylinders connected to one crank, and the low to another crank at right angles. All cylinders and receivers are jacketed with steam at the boiler pressure of 145 lbs. As in the case of the *Meteor* and *Iona*, no priming tests were made, but drip-water from the steam supply pipe was drawn off through a separator to the amount of 1.34% of the feed-water. This drip-water is not included in the water consumption given in the tables. The ratio of possible expansion was 24.0. Applying the analysis we have, Table IV. :

$$F = 85\%\ ;\ 100 + S = 117\%\ ;\ 100 - S' = 86\%.$$

Compared with the high boiler pressure tests of the Laketon engine, we find that W is 7.95 for the Sulzer as compared with 8.18 for Laketon, and this advantage, together with the less cylinder condensation in the high cylinder, and less jacket expense, is in favor of economy to such a degree as to more than counterbalance the superiority of the Laketon in value of F, or loss of area, so that the actual water consumption is about 7% less than that of the Laketon engine.

4th. The test of a Wheelock triple 190 H. P. engine, made by Messrs. Rockwood and Green (Fig. 436), which, next to those of the Sulzer engine, show the lowest water consumption per horse-power. They have excited special interest among students of

* *Vide* pamphlet by Professor Schroter, to whose courtesy the writer is indebted for the data used.

steam-engine tests, because the high and low cylinders, used as a compound engine to develop the same horse-power as the triple arrangement at the same boiler pressure, approximated very closely in economy to the latter. The results of the analysis applied to these tests are given in Table IV., and their discussion is as follows:

WHEELOCK ENGINE, TRIPLE AND DOUBLE COMPOUND.
TEST BY ROCKWOOD AND GREEN.

The following are the data given in the paper of Messrs. Rockwood and Green, Vol. XIII. page 647, *Transactions*, A.S.M.E.:

DIMENSIONS OF ENGINE.

	H. P.	Int.	L. P.
Diameter of cylinder	12″	16″	24½″
Diameter of piston-rod	2 & 2¾″	2″	3¼″
Stroke of piston	36″	36″	48
Clearance in per cent. of piston displacement	2%	4%	3%
Inside diameter of steam pipe	5″	6″	9″
Inside diameter of exhaust pipe	6″	7″	10″
Area of steam port	13″	21″	38″
Area of exhaust port	16.5″	25″	60″

GENERAL RESULTS OF FOUR TESTS OF A TRIPLE-COMPOUND ENGINE, RUN BOTH AS A TRIPLE AND AS A DOUBLE COMPOUND.

Test.	Engine.	Duration, hours.	R. P. M.	Average steam pipe press.	Average indicated horse power.	Water per I. H. P. per hour. Lbs.	Dry steam per I. H. P. per hour. Lbs.	Weight of water used in jackets per hour. Lbs.
A	12 x 36 / 24½ x 48	5 [7-12]	79.2	142	187.11	13.41	13.06	330.3
B	12 x 36 / 24½ x 48	5 [1-6]	79.3	142	180.71	13.11	12.76	330.3
C	12⅛ x 36 / 24½ x 48	5 [7-12]	79.0	142	199.08	13 01	12.67	416.0
D	12⅛ x 36 / 24½ x 48	5 [1-6]	79.0	143	178.16	13.25	12.90	388.8

All cylinders and receivers jacketed with live steam at boiler pressure.

Using the sample cards * given in the paper, we have the combined cards in Fig. 436. In the triple tests the high card has no area beyond six-tenths of stroke, owing to the lifting of the exhaust valve at this point.

The cut-off in the high cylinder in the compound test is 18.5% of stroke, and 58% of the clearance space must be filled, as the cushion is incomplete. The initial Mariotte volume 1, 2, is therefore $0.185 + 0.58 \times 0.02 = 0.197$. The possible ratio of expansion is, therefore, 30.8, and the Mariotte card is 1, 2, 3, 4, 5, 6. In the triple test the cut-off in high cylinder is 22% of stroke, and the cushioning is carried to boiler pressure. The possible ratio of expansion is, therefore, 28.2, and the Mariotte card is 7, 8, 9, 4, 5, 10.

Applying the foregoing method of analysis we find, per Table IV., that the compound should use theoretically 7.68 lbs. per hour per horse-power, and the triple 7.8 lbs.

The "drop" between the intermediate and low cylinders, together with the loss of area between the exhaust and admission lines of these two cylinders, makes the aggregate area of the triple cards 95% of the theoretical card against 94% for the compound cards. The latter has a greater "drop" between high and low cylinders, but no loss between the admission and exhaust lines. The losses are, therefore, practically equal as regards mean effective pressure.

By the combined effect of the jacket expense, cylinder condensation, and loss of theoretical area, the consumption for the compound becomes $W_4 = \frac{7.68 \times 1.16}{0.724 \times 0.94} = 7.68 \times 1.706 = 13.11$ lbs. and for the triple $W_4 = \frac{7.8 \times 1.2}{0.076 \times 0.95} = 7.8 \times 1.682 = 13.01$ lbs. It is seen that the superiority due greater expansion of the compound is neutralized by these factors.

The cylinder condensation of the compound is normal † for the range of temperature and speed, and probably cannot be much reduced. The cylinder condensation of the triple is, on the other hand, perhaps 10% greater than the best precedent,

* These cards show slightly less M. E. P.'s than agree with the horse-power as given above. The deductions made from them are not, however, liable to any important error on this account, as they deal only with relative proportions of the cards.

† See Pawtucket Engine Cylinder Condensation. *Transactions*, A. S. M. E., Vol. XI.

considering the range of temperature and cut-off in high cylinder, and that the jacket-water is 20%. (Compare results of the Sulzer engine, Tables III and IV.) It is probable, therefore, that the peculiar condition of the steam action in the high cylinder of the triple engine prevented it from deriving the proper benefit due to the triple-expansion principle of the sub-divided temperatures.

GENERAL CONCLUSIONS.

I.

In the Laketon engine, with cylinders $24\frac{1}{8} \times 34$, and 54×36 stroke, at about 28 revolutions per minute.

(1) A water consumption of 13.84 lbs. per hour per horse-power, at 20 expansions, with 2.5% moisture in steam, or 13.5 lbs. of dry steam, appears to be available at 150 lbs. boiler pressure by the use of any pressure between 43 and 131 in the intermediate and low jackets and re-heaters, either with 150 lbs. in the high cylinder jacket, or with no steam in the latter, since the differences of water consumption within the range of these conditions are no greater than the variations due to the one per cent. of accidental error to which the results are liable.

(2) The use of jackets and re-heaters for the intermediate and low cylinders, with 150 lbs. boiler pressure, and 15 expansions, increases the water per hour per horse-power 8.3% * over that obtained with the jackets and re-heaters in use at 20.5 expansions, and it is probable that a greater per cent. of loss would occur if more than 15 expansions were used without the jackets and re-heaters.†

(3) The use of 113 lbs. boiler pressure, and 13.5 expansions, with jackets and re-heaters, increases the water consumption per hour per horse-power only 3.5% as compared to the use of 150 lbs. boiler pressure and 20.5 expansions. The difference in the ratio of expansion should cause about 13% increase in steam consumption, but there is a gain with the low pressure due to less expense of jacket steam, and less cylinder condensation in the high cylinder, with the lower boiler pressure, sufficient to cause the difference of economy realized by the high pressure to be only 3.5%.

* Read 1.9%. See foot note, page 1357.

† This gain in *water consumption* is equivalent to 5.2% gain in *fuel consumption*, if the steam condensed in the jackets and receivers is returned to the boiler by mixing with the feed-water.

II.

The best economy yet recorded for triple-expansion engine is 12.73 lbs. of feed-water per hour per English * horse-power. This has been satisfactorily shown by a Sulzer Corliss engine in Germany, with cylinders 19.75″ x 29.6″ x 47.35″ x 55.2″ stroke, at 66.4 revolutions per minute, 145 lbs. boiler pressure, and about 24 expansions, with all cylinders and receivers jacketed with live steam at boiler pressure.

III.

Possibly the same economy, or at most 13.35 lbs. of water per horse-power, has been obtained with the engines of the S. S. *Iona*, with cylinders 21.88 x 34 x 54, and 39″ stroke, 61.1 revolutions per minute, and 180 lbs. boiler pressure, with the high cylinder barrel only † jacketed, and with a link-motion valve-gear.

IV.

The greater water consumption of the Laketon engine compared with these two engines is due to less jacket-water expense, and less cylinder condensation in the high cylinder in the case of the Sulzer engine, and to the former item alone in the case of the *Iona*. The Laketon engine realizes a greater per cent. of the theoretically possible M. E. P. due to its ratio of expansion than either the Sulzer or *Iona* engines, but it is not as perfect in this respect as the Wheelock engine tested by Messrs. Rockwood and Green. The slower speed of rotation of the Laketon probably causes its greater expense of steam in jackets, and during admission to the high cylinder.

V.

The best results with the triple engines support the theory that less expense of steam in cylinder condensation during admission to the high cylinder occurs when the range of temperature between 150 lbs. and exhaust pressure in the low cylinder is divided into three parts, than when the range is divided into two parts in a bi-compound system.

* An English horse-power is equal to the $\frac{\text{Metric horse-power}}{0.986}$. The tests of the Sulzer engine show 12.53 lbs. of water per hour per indicated metric horse-power.

† See remarks of Mr. Hall in discussion, regarding peculiar design of this jacket, so that it could serve partly as a re-heater for the intermediate and low receivers.

VI.

The foregoing results, as a whole, support the theory that with condensing engines, up to at least 24 expansions, the economy increases with increase in the ratio of expansion, that cylinder condensation during admission to the high cylinder is slightly reduced with increase of speed of rotation between 28 and 66 revolutions per minute, and in a greater degree by reduction of range of temperature. Also that jacketing, at least on all parts except the high cylinder, is necessary to make *certain* of the highest possible economy of fuel with a given range of expansion, but the gain of fuel by jacketing may be such that, where the latter is cheap, the cost of jackets and the care necessary to operate them may make them an undesirable complication in an engine's design.

PERFORMANCE OF BOILERS BURNING PETROLEUM AS FUEL.

The following are the results of the evaporation tests made on the two boilers at Laketon, Indiana, which supplied steam to the triple-expansion pumping-engine under notice :

The fuel used was crude petroleum, burned in a Cobb & Towl compressed-air burner.

The boilers were of the horizontal return tubular type, five feet diameter, fourteen feet long, and containing 182 two-inch tubes.

The oil burner was located at the front end of the boiler, and the products of combustion passed under the latter, through the tubes, and thence to the chimney.

The water-heating surface of each boiler was 1180 square feet. There was no superheating surface.

The average evaporation, from and at 212° Fahr., for the seven tests detailed in the following table, was 16.10 lbs. of water per pound of oil.

The quality of the steam, as determined by a superheating calorimeter, was perfectly dry.

The average evaporation per hour per square foot of heating surface was 1.9 lbs. at 150 lbs. gauge pressure, and 60° temperature of feed-water.

The boilers had been thoroughly cleaned on March 30th. The boilers were new, having been in service about two months.

The flues were thoroughly cleaned on March 30th, and again on April 3d.

The temperature of the gases entering the chimney was about 385° Fahr. A determination of the temperature of the flame at the bridge-wall showed it to be about 1534° Fahr.

TABLE VI.

RESULTS OF TESTS OF TUBULAR BOILERS BURNING PETROLEUM AT LAKETON, INDIANA.

Date.	Duration of test in hours.	Average boiler pressure.	Lbs. of oil consumed per hour.	Lbs. of feed-water per hour.	Lbs. of water per lb. of oil, actual steam pressure and 90° feed temperature.	Evaporation per lb. of oil from and at 212° Fahr.
March 31...	6	151	311.1	4,351	13.99	16.37
April 1.....	5	151	323.6	4,469	13.81	16.16
April 2.....	6	150	325.8	4,429	13.59	15.90
April 4.....	8	113	350.3	4,617	13.18	15.29
April 5.....	3	151	325.0	4,622	14.22	16.64
Apr. 5 and 6.	12	151	335.0	4,475	13.36	15.63
April 6.....	5	151	330.0	4,563	13.83	16.18
April 6.....	8	152	326.5	4,416	13.52	15.81

The oil burner was supplied with air at about one-half pound pressure per square inch, by a Root blower delivering 240 cubic feet of air per minute, and driven by a small steam engine, whose steam consumption amounted to about 1½% of the steam evaporated by the boiler.

TABLE VII.

Test No. 1. March 31.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
1	51.0	50.0	50.5	11.75	11.50	11.6	11.75	12.25	12.0
2	49.25	56.0	52.6	12.0	12.0	12.0	11.88	11.50	11.6
3	54.0	50.0	52.0	11.9	12.5	12.2	11.75	12.0	11.8
4	53.0	51.0	52.0	12.25	12.75	12.5	11.75	12.0	11.8
5	52.5	..	...	12.0	12.0	12.0	11.88	11.88	11.9
6	52.5	51 5	52.0	12.0	12.25	12.1	12.12	11.62	11.9
7	54.0	53.0	53.5	12.25	12.5	12.3	11.75	11.75	11.8
8	52.5	49.0	50.8	13.0	12.25	12.6	12.0	11.75	11.8
9	51.5	50.0	50.8	12.5	12.0	12.2	11.38	12.0	11.7
10	52.5	54.0	53.2	12.12	12.0	12.0	11.38	11.62	11.5
11	52.0	48.0	50.0	12.0	12.0	12.0	11.25	12.38	11 8
12	51.0	....	....	12.5	12.5	12.5	12.0	11.6	11.8
13	47.0	52.0	49.5	12.75	12.25	12.5	11.2	11.5	11.4
	Average.....		51.5	.....	.....	12.2	....	.....	11.75

TABLE VIII.

TEST NO. 2. APRIL 1.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
14	44.0	45.0	44.5	15.2	14.2	14.7	11.8	11.9	11.8
15	48.0	46.0	47.0	14.2	14.5	14.4	11.8	12.0	11.9
16	46.5	46.0	46.2	14.0	14.3	14.2	11.9	12.1	12.0
17	47.5	45.0	46.2	14.5	15.25	14.8	12.2	12.6	12.4
18	46.5	44.5	45.5	14.25	14.5	14.8	12.0	12.25	12.1
19	46.5	44.0	45.2	14.0	15.5	14.7	12.0	12 0	12.0
20	46.0	45.0	45.5	14.2	15.1	14.6	11.8	12.3	12.0
21	45.0	43.5	44.2	14.0	14.6	14.3	12.0	12.3	12.2
22	46.5	44.(	45.2	14.3	14.9	14.6	12.2	12.2	12.2
23	46.0	43.5	44.8	14.1	14.2	14.2	12.0	12.4	12.2
24	45.5	43.0	44.2	13.8	14.2	14.0	11.9	12.1	12.0
	Average.....		45.3	.....	.....	14.5	.....	.....	12.1

TABLE IX.

TEST NO. 3. APRIL 2.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
30	55.2	52.0	53.6	11.24	11.24	11.2	11.5	11.5	11.5
31	53.8	53.0	53 4	11.24	11.6	11.4	11.3	11.4	11.4
32	54.6	54.6	54.6	11.58	11.7	11.7	11.35	11.35	11.4
33	54.8	54.6	54.7	12.0	12.4	12.0	11.25	11.2	11.2
	Average.....		54.1	.....	.....	11.6	.....	.....	11.4

TABLE X.

Test No. 4. April 4.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
40	43.5	43.7	43.6	13.1	13.2	13.1	12.75	12.75	12.75
41	45.0	42.0	43.5	13.4	13.1	13.2	12.6	12.9	12.8
42	47.0	42.0	44.5	13.3	13.3	13.3	12.9	13.2	13.0
43	46.0	41.0	43.5	13.0	13.4	13.2	12.7	12.75	12.8
44	46.5	41.0	43.8	13.0	13.1	13.0	12.9	12.8	12.8
45	44.25	40.5	42.8	13.2	12.8	13.0	12.7	13.0	12.8
46	46.0	40.5	43.2	12.7	13.25	13.0	12.7	12.8	12.8
	Average		43.6	.....	.....	13.1	.....	.....	12.8

TABLE XI.

Test No. 5. April 5.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
60	66.0	63.5	64.8	16.8	18.2	17.5	7.2	7.0	7.1
61	65.5	63.5	64.5	17.2	18.7	18.0	7 0	6.8	6 9
62	65.0	65.0	65.0	17.5	18.9	18.2	7.0	8.1	7.6
63	66.0	61.0	63.5	17.3	18.5	17.9	6.5	6.5	6.5
	Average		64.4	.....	.....	17.9	.....	.....	7.0

TABLE XII.

Test No. 6. April 5 and 6.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
72	50.0	45.0	47.5	14.3	14.54	14.42	11.25	10.95	11.10
73	52.96	47.6	50.28	13.18	13.94	13.56	12.18	11.5	11.84
74	54.8	48.72	51.76	13.36	13.44	13.4	11.82	11.42	11.62
75	53.52	48.08	50.8	12.84	13.34	13.09	11.5	11.1	11.3
76	58.72	47.68	50.2	13.06	14.12	13.59	11.66	11.25	11.46
77	53.44	48.0	50.72	13.06	13.3	13.18	11.6	11.03	11.32
78	53.44	48 40	50.92	12.5	12.96	12.73	11.38	10.85	11.12
79	54.4	49.2	51.8	12.26	13.34	12.8	11 32	10.74	11.03
80	53.28	48.4	50.84	12.56	13.0	12.78	11.21	10 98	11.1
81	53.6	48.4	51.0	12.46	12.74	12.6	11.28	10.94	11.09
82	52.64	48.96	50.3	12.6	13.2	12.9	11.24	10.9	11.07
83	55.0	50.0	52.5	13.2	12.8	13.0	11.33	11.0	11.16
	Average		50.7	.....	.....	13.2	.....	.....	11.3

TABLE XIII.

Test No. 7. April 6.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
90	54.4	49.2	51.8	13.58	13.34	13.41	11.15	10.78	10.06
91	54.96	50.0	52.48	13.44	13.24	13.34	11.22	10.7	10.96
92	54.0	50.32	52.16	13.22	13.0	13 11	11.05	10.7	10.88
93	55.52	50.0	52.76	13.06	13.12	13.09	10.93	10.52	10.72
94	56.24	50.0	53.12	13.94	13.6	13.77	11.27	10.6	10.98
	Average		52.46	.....	.....	13.3	.....	.....	10.9

TABLE XIV.

Test No. 8. April 6.

MEAN EFFECTIVE PRESSURES, LBS. PER SQUARE INCH.

No. of Card.	High Pressure Cylinder.			Intermediate Cylinder.			Low Pressure Cylinder.		
	Left.	Right.	Average.	Left.	Right.	Average.	Left.	Right.	Average.
96	57.6	50.0	53.8	9.0	8.2	8.6	12.8	12.3	12.55
97	56.8	52.0	54.4	8.62	8.04	8.33	10.12	12.1	11.11
98	54.0	48.8	51.4	9.46	9.3	9.38	12.94	12.24	12.59
99	54.16	49.6	51.88	9.22	9.16	9.19	12.6	11.99	12.3
100	53.04	49.6	51.32	9.14	9.42	9.28	12.76	12.4	12.58
101	53.6	48.8	51.2	9.64	9.34	9.49	12.4	12.2	12.3
	Average		52.3	.....	.... :	9.0	.....	.....	12.2

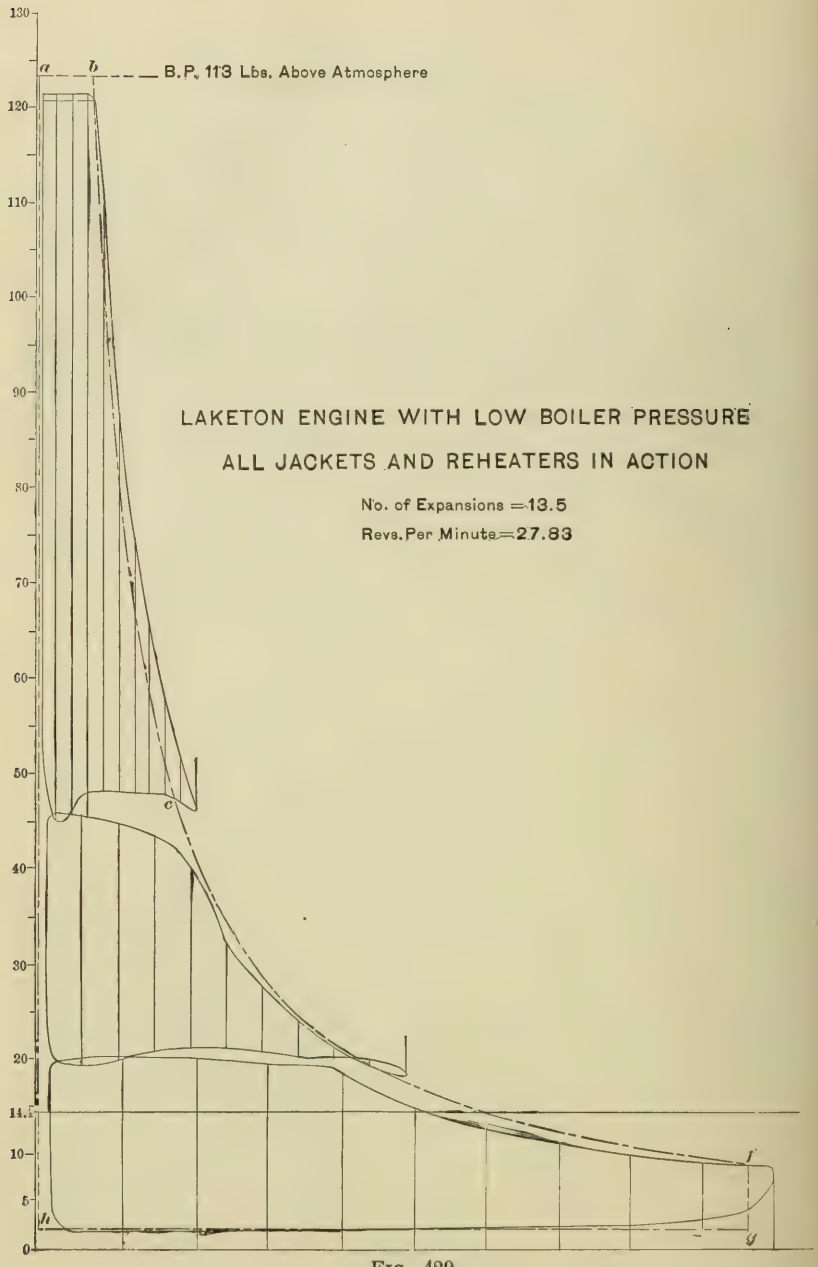

130
120
110
100
90
80
70
60
50
40
30
20
14.5
10
5
0
a
b
B.P. 113 Lbs. Above Atmosphere
LAKETON ENGINE WITH LOW BOILER PRESSURE
ALL JACKETS AND REHEATERS IN ACTION
No. of Expansions = 13.5
Revs. Per Minute = 27.83
c
f
g

FIG. 429.

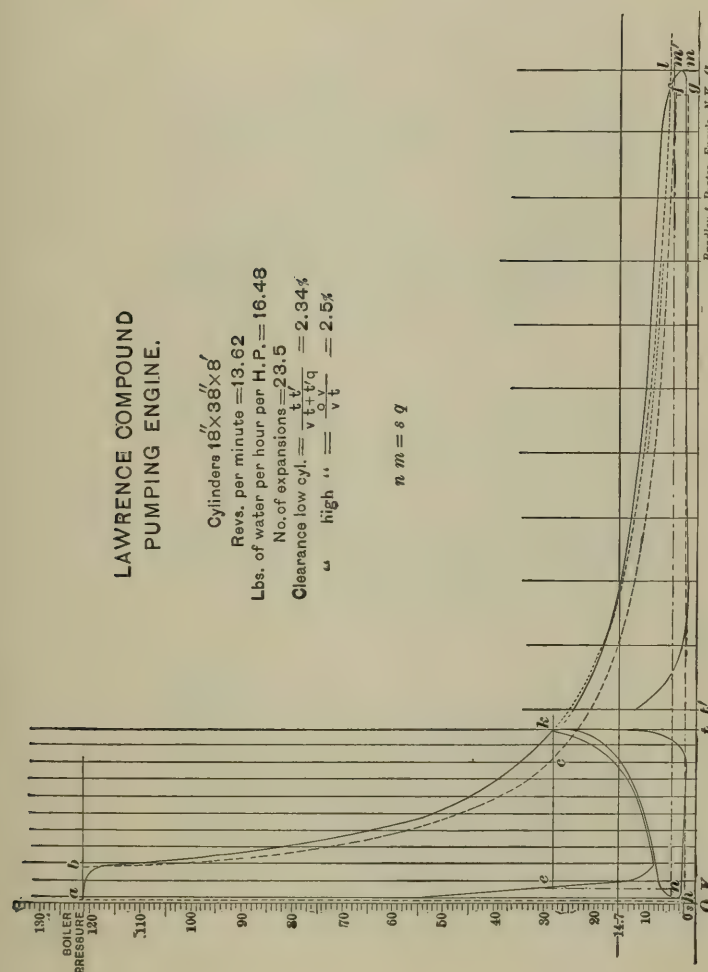

LAWRENCE COMPOUND
PUMPING ENGINE.
Cylinders 18″×38″×8′
Revs. per minute =13.62
Lbs. of water per hour per H.P. = 16.48
No.of expansions=23.5
Clearance low cyl. = $\frac{t\,t'}{v\,t+t'q}$ = 2.34%
" high " = $\frac{o\,v}{v\,t}$ = 2.5%
n m = s q
BOILER PRESSURE
Bradley & Porter, Engr's, N.Y.

Fig. 432.

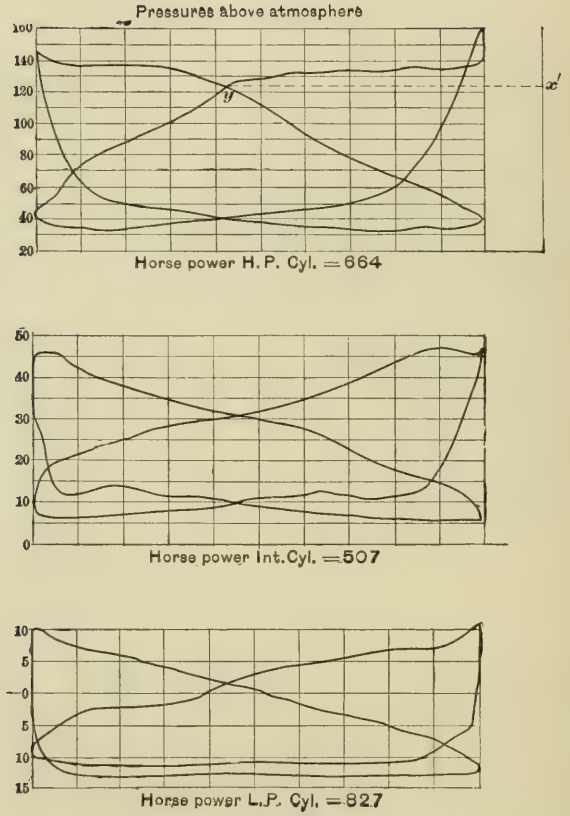


FIG. 431.

Cards from S.S. *Meteor*.

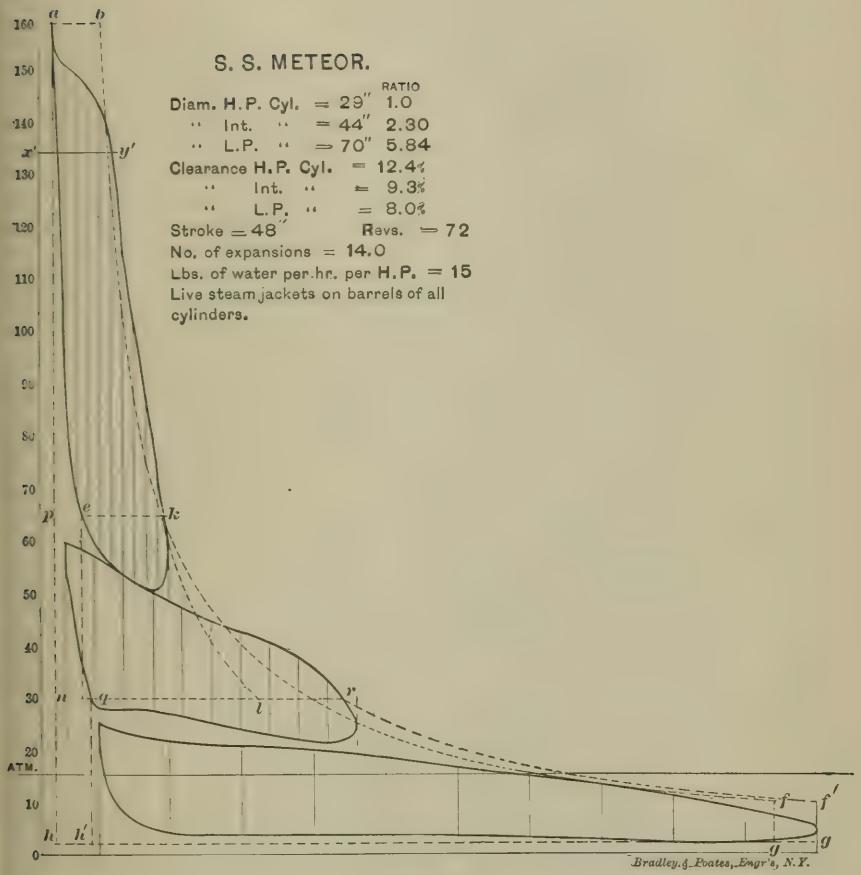

S. S. METEOR.
RATIO
Diam. H.P. Cyl. = 29" 1.0
" Int. " = 44" 2.30
" L.P. " = 70" 5.84
Clearance H.P. Cyl. = 12.4%
" Int. " = 9.3%
" L.P. " = 8.0%
Stroke = 48" Revs. = 72
No. of expansions = 14.0
Lbs. of water per hr. per H.P. = 15
Live steam jackets on barrels of all cylinders.
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
ATM.
10
0
a
b
x'
y'
p
e
k
n
q
l
r'
f
f'
h
h'
g
g
Bradley, Fowles, Engr's, N.Y.

FIG. 433.

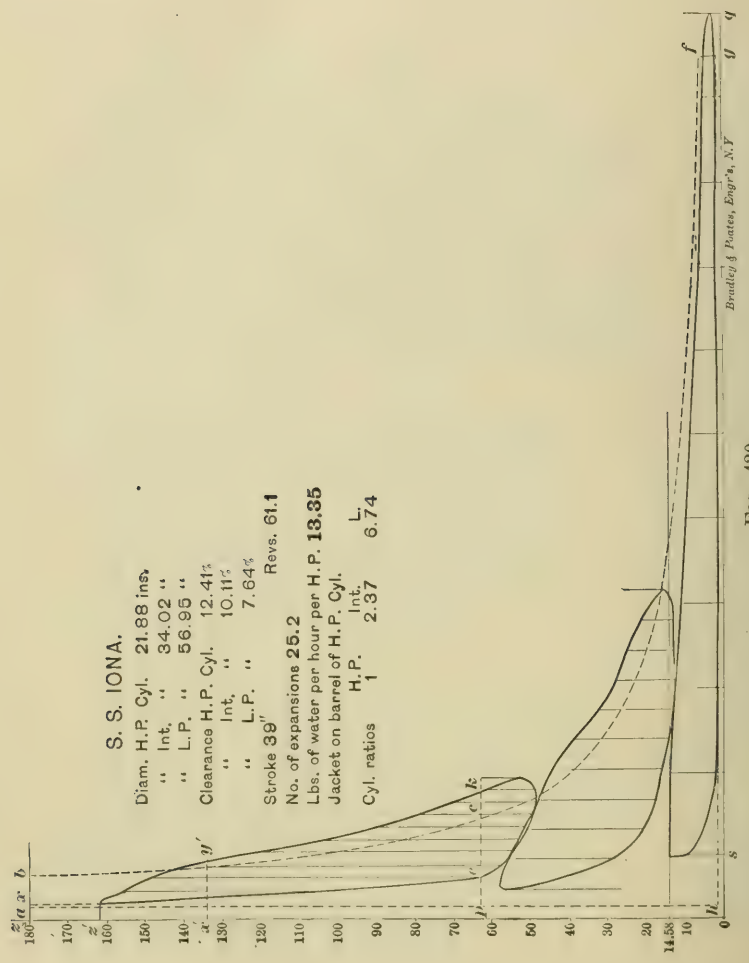

S. S. IONA.
Diam. H.P. Cyl. 21.88 ins.
" Int, " 34.02 "
" L.P. " 56.95 "
Clearance H.P. Cyl. 12.41%
" Int, " 10.11%
" L.P. " 7.64%
Stroke 39" Revs. 61.1
No. of expansions 25.2
Lbs. of water per hour per H.P. 13.35
Jacket on barrel of H.P. Cyl.
H.P. Int. L.
Cyl. ratios 1 2.37 6.74
Bradley & Pirates, Engr's, N.Y.

FIG. 430.

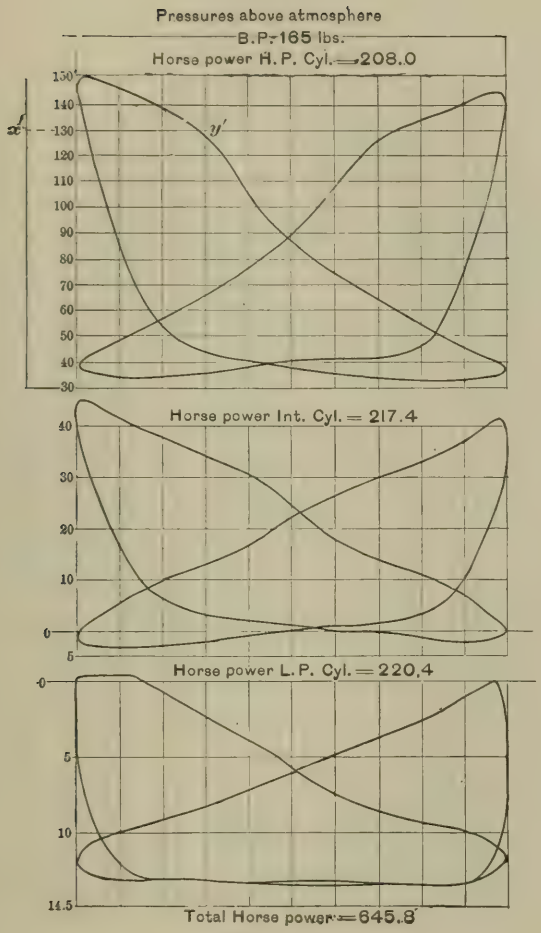


FIG. 434.
Cards from S.S. *Iona*.

FIG. 435.

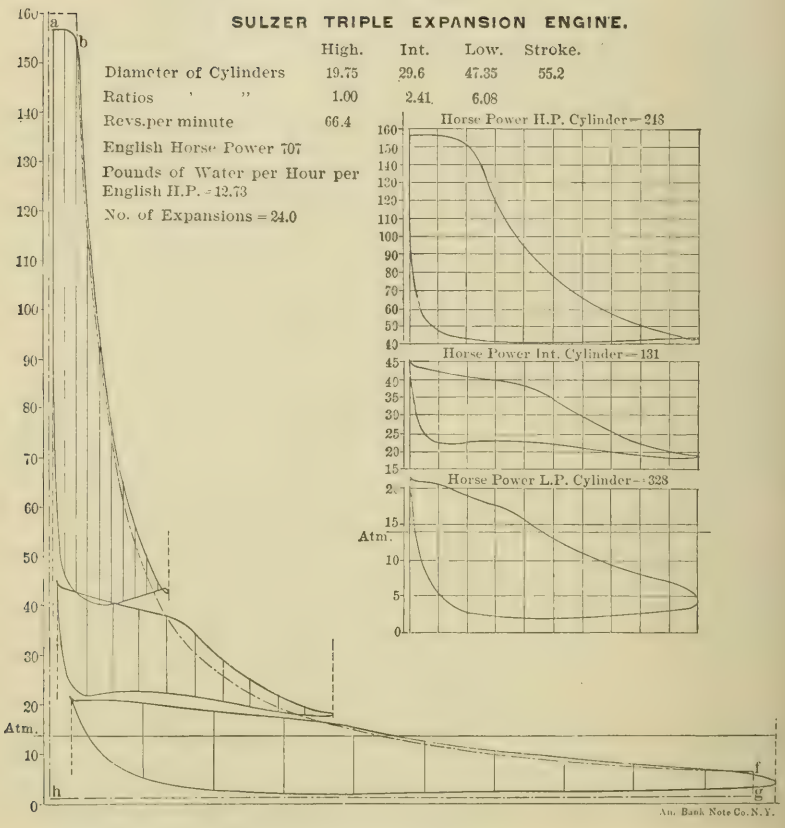

SULZER TRIPLE EXPANSION ENGINE.
High. Int. Low. Stroke.
Diameter of Cylinders 19.75 29.6 47.35 55.2
Ratios " " 1.00 2.41 6.08
Revs. per minute 66.4
English Horse Power 707
Pounds of Water per Hour per English H.P. = 12.73
No. of Expansions = 24.0
Horse Power H.P. Cylinder = 248
Horse Power Int. Cylinder = 131
Horse Power L.P. Cylinder = 328
Atm.
a
b
f
g
h
Am. Bank Note Co. N.Y.

FIG. 436.

CARDS OF TRIPLE AND BI-COMPOUND TESTS OF WHEELOCK ENGINE BY ROCKWOOD & GREEN.

Cylinders { 12″ x 34″ x 3′ / 36″ x 4′

Revolutions per minute = 79

Lbs. of Water per hour per H.P. = 13.01 — 13.11

	Triple.	Compound.
No. of Expansions	28.2	30.8

AREAS OF CARDS

Triple — Full Lines ———
High 1.10
Int. 1.25
Low 2.50
4.85 a″

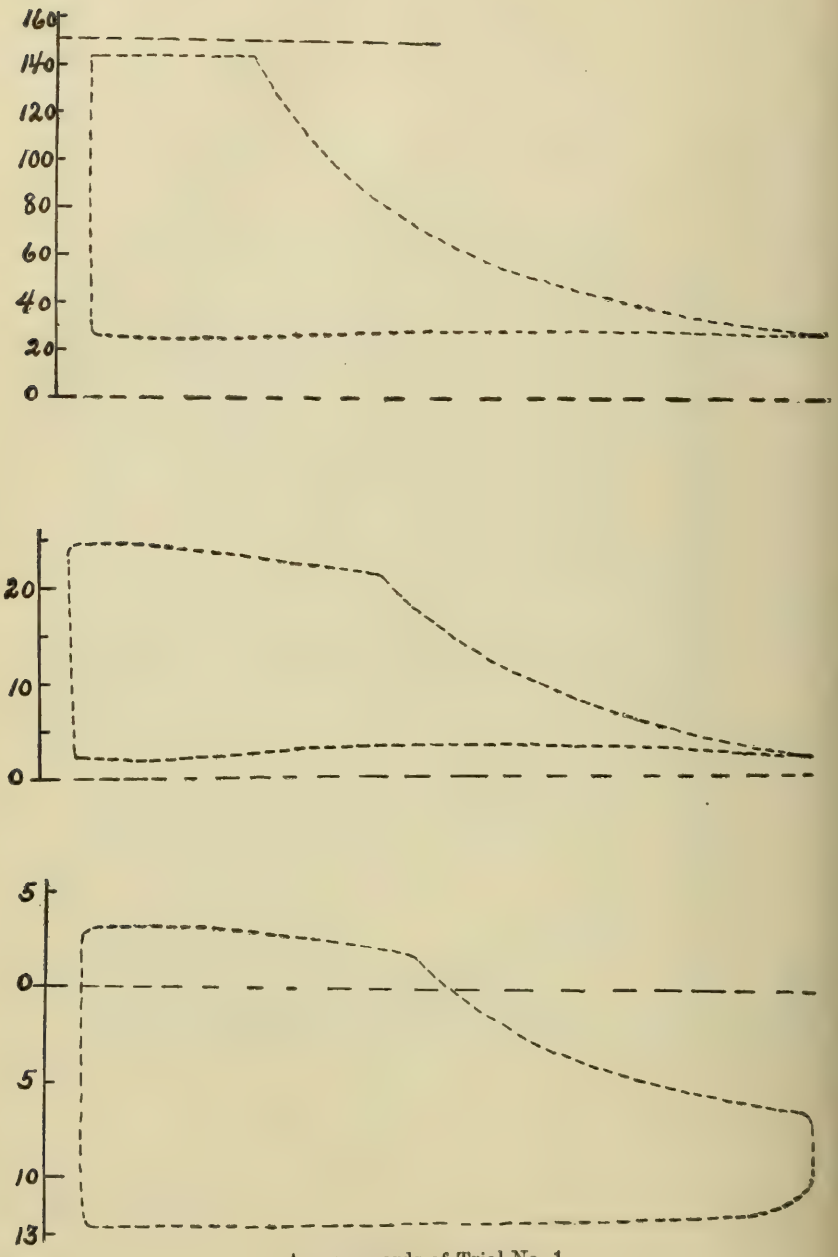
Compound — Dotted Lines – – – –
High 2.1
Low 2.5
4.6 a′

Marriottes 1,2,3,4,5,6
Dot and Dash —·—·—·— 5.12 a″
28.2 Expansions
Ratio = $\frac{4.85}{5.12}$ = 0.95

Marriottes 7,8,9,4,5,10
4.9 a′
30.8 Expansions
Ratio = $\frac{4.6}{4.9}$ = 0.94

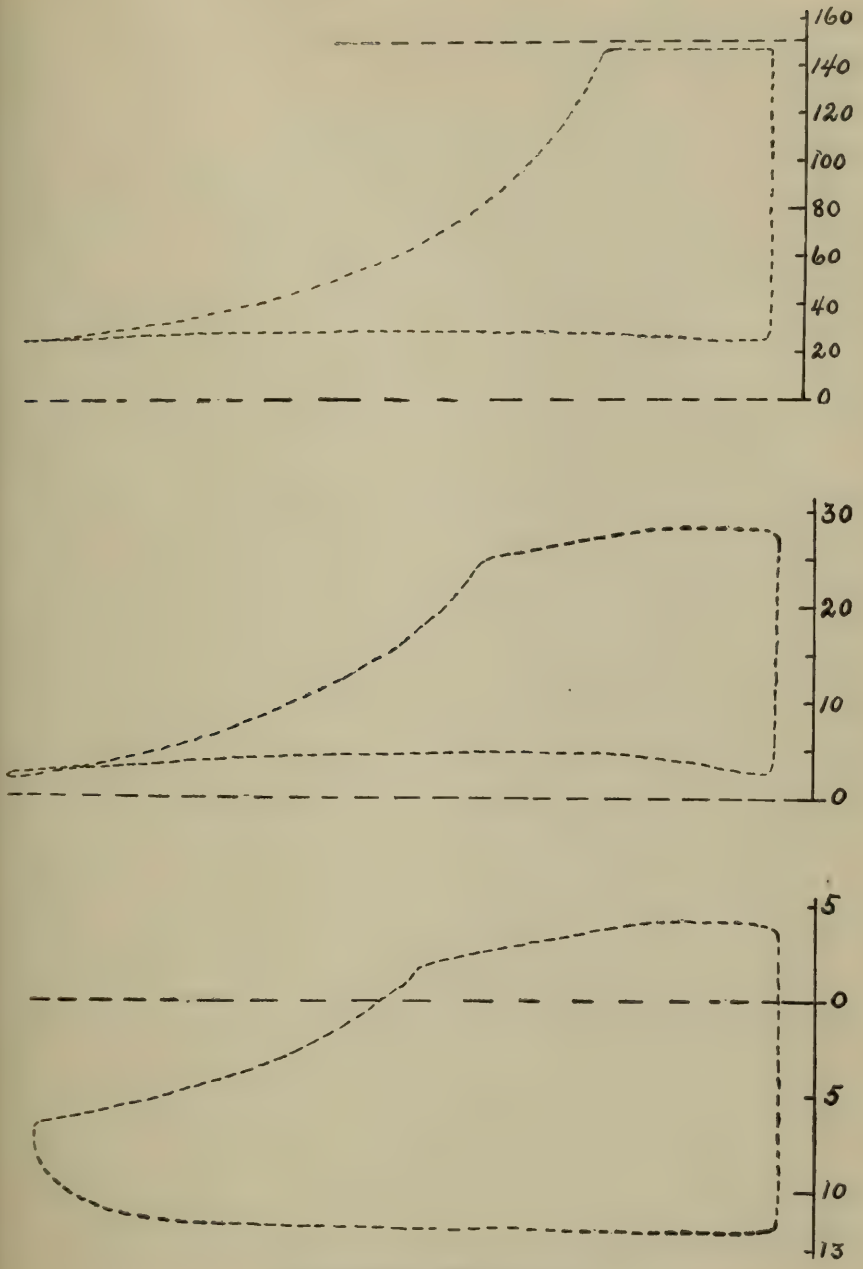
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 14.7 10 0

Am. Bank Note Co. N.Y.



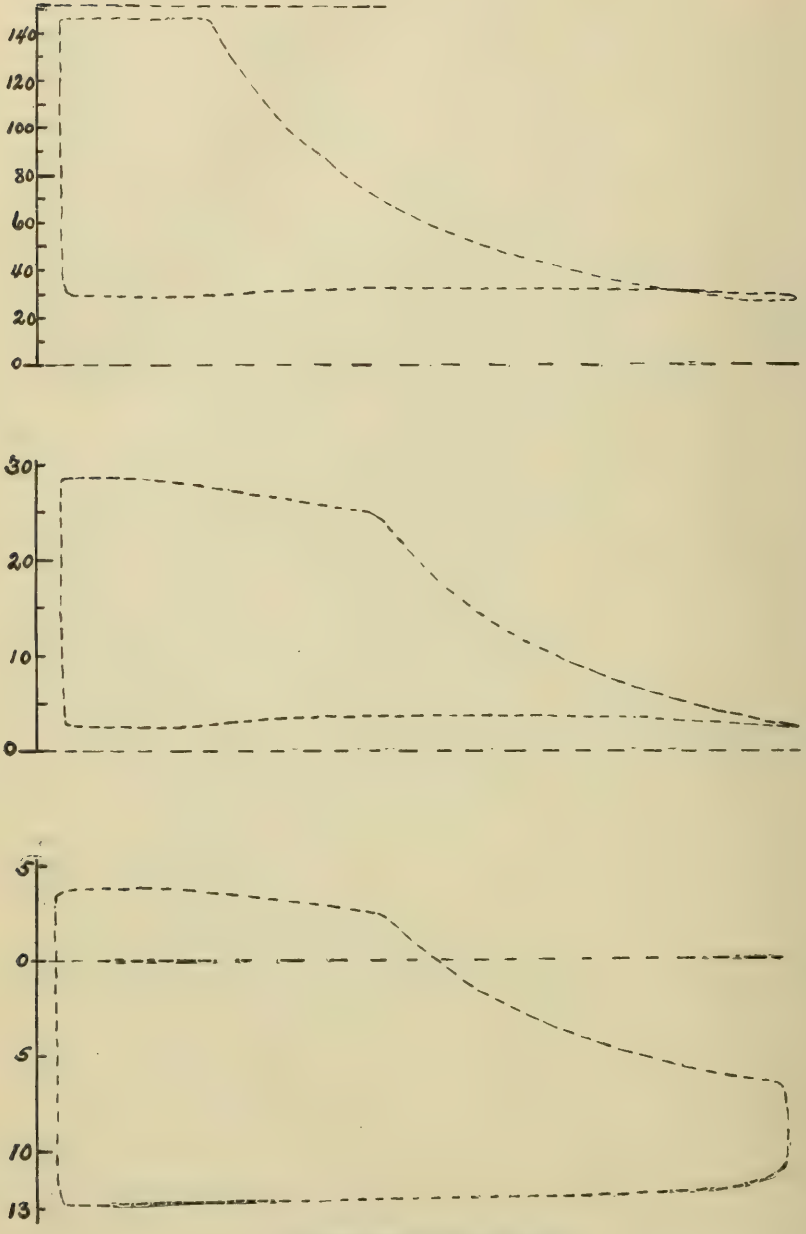
Average cards of Trial No. 1.

FIG. 437.



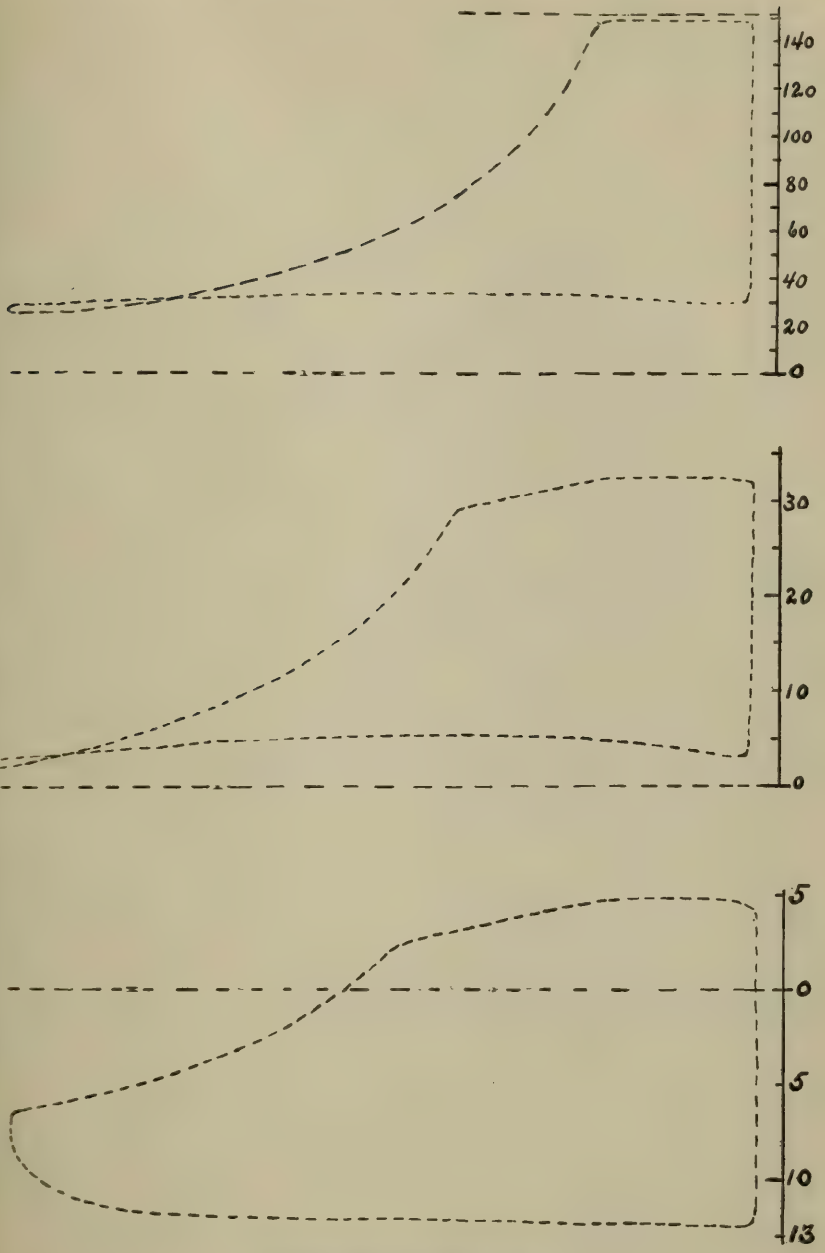
Average cards of Trial No. 1.

FIG. 438.



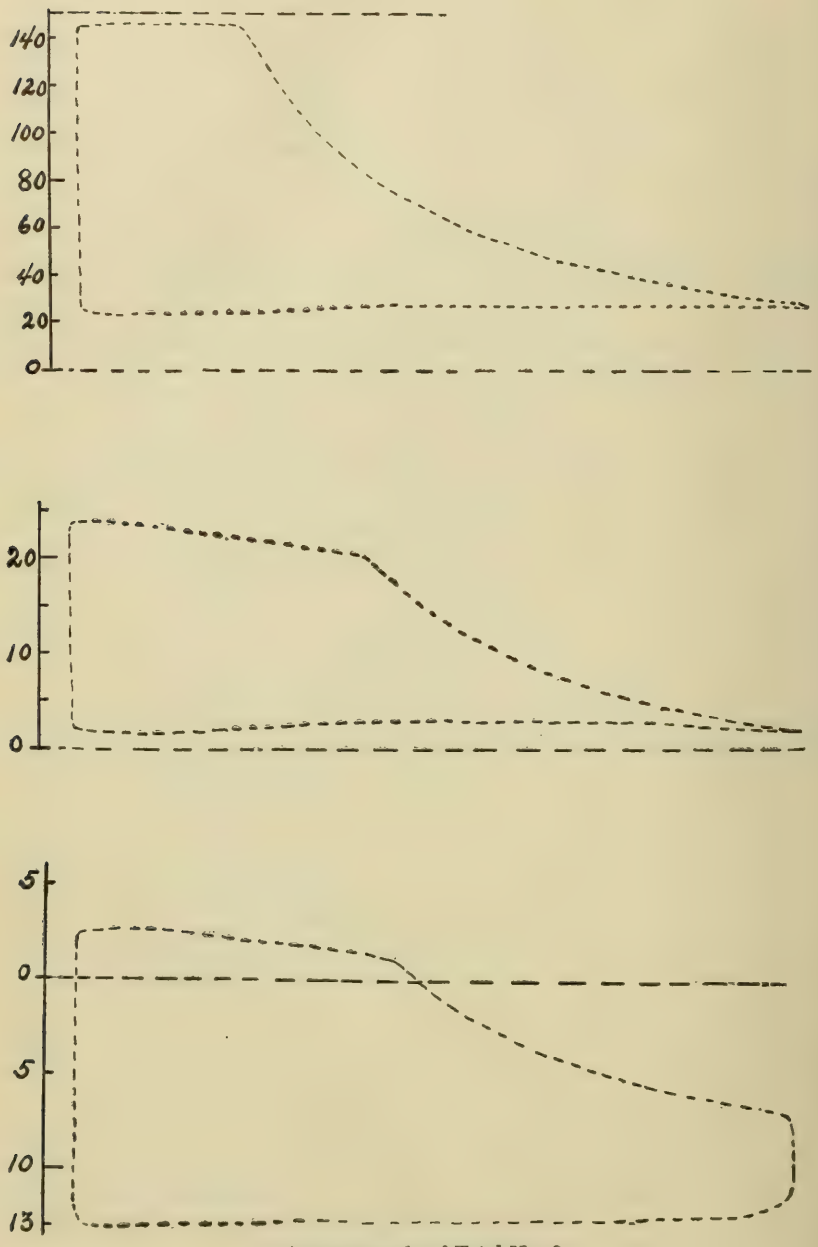
Average cards of Trial No. 2.

FIG. 439.



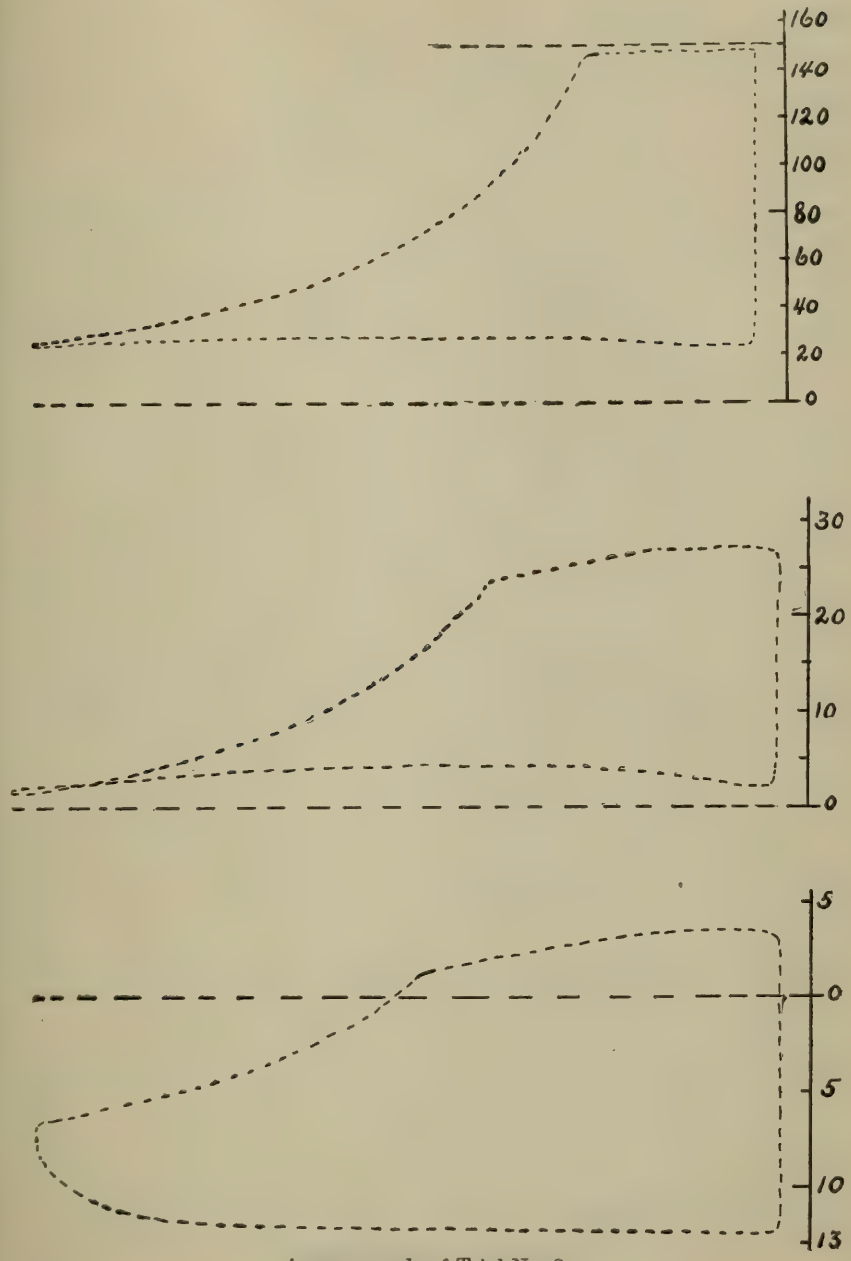
Average cards of Trial No. 2.

FIG. 440.



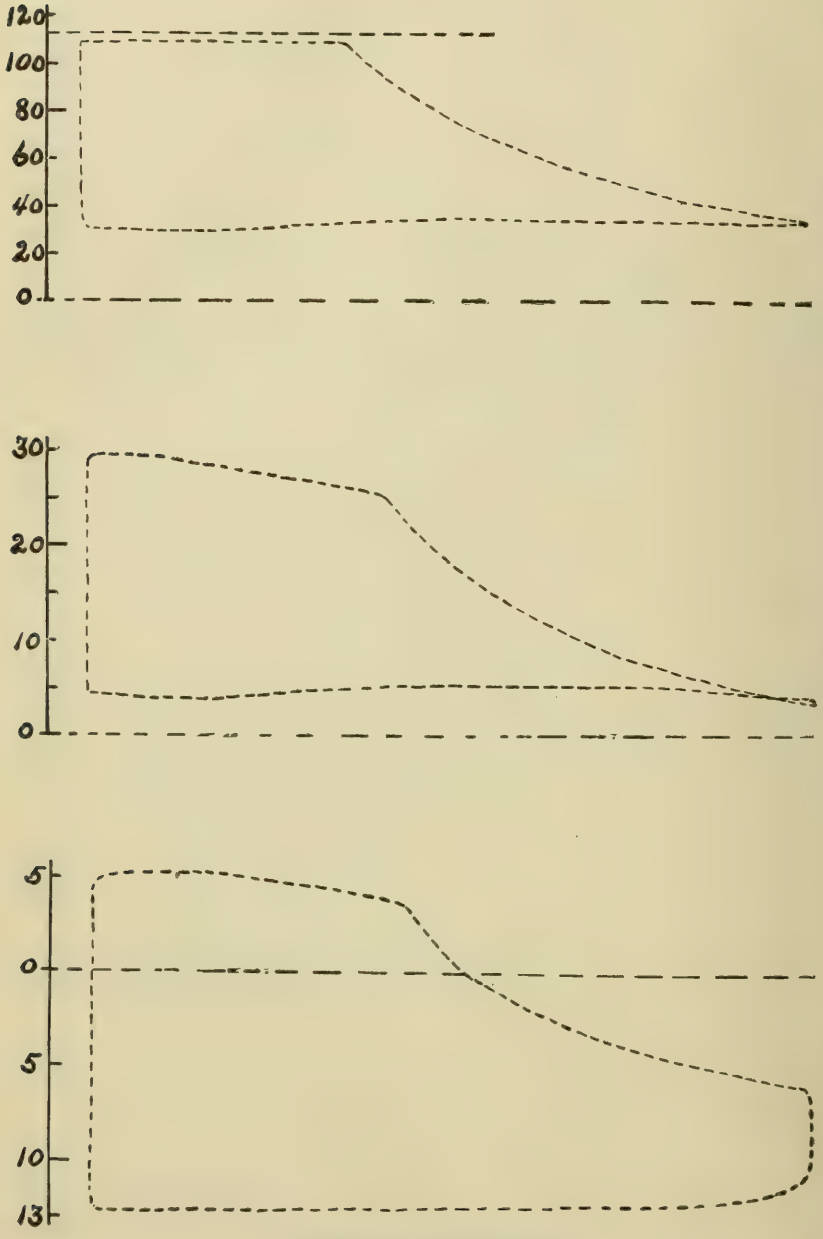
Average cards of Trial No. 3.

FIG. 441.



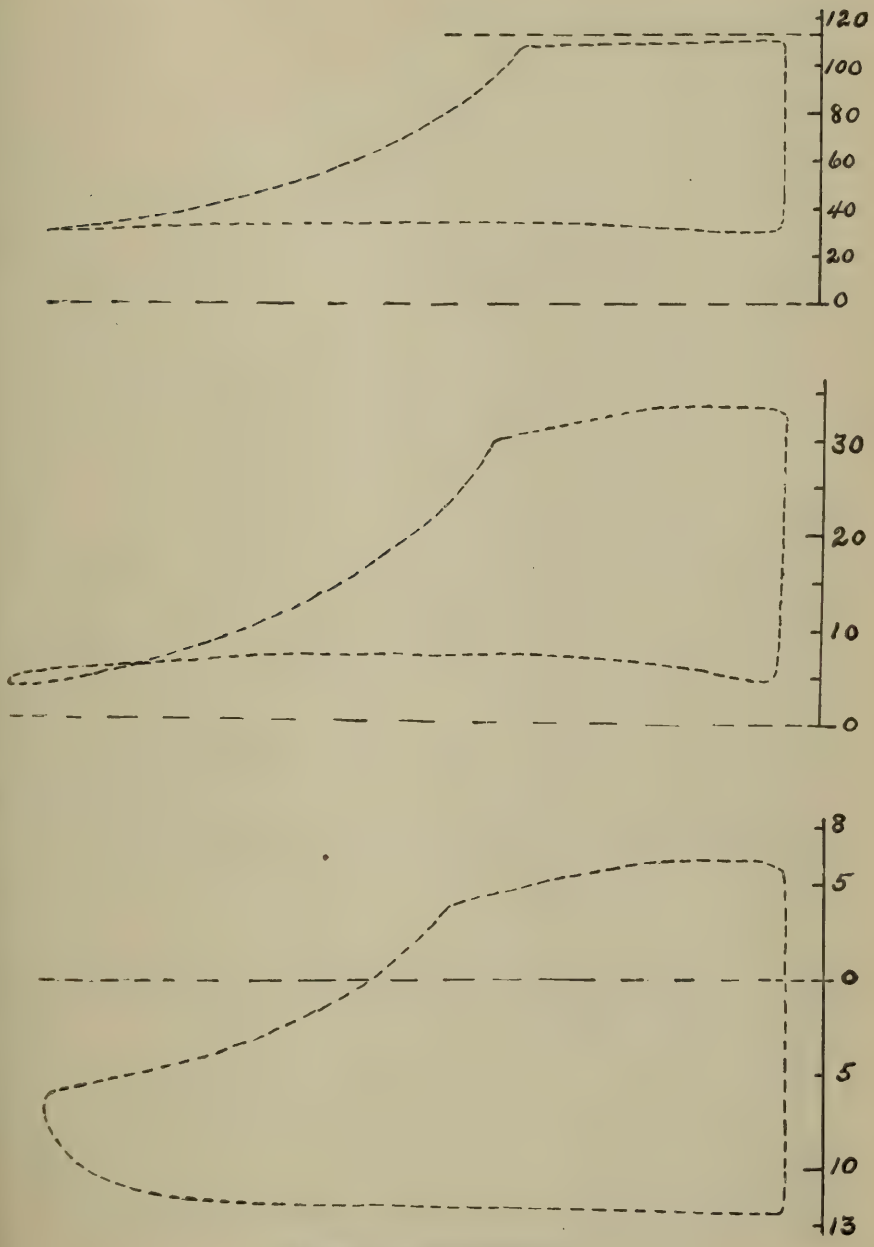
Average cards of Trial No. 3.

FIG. 442.



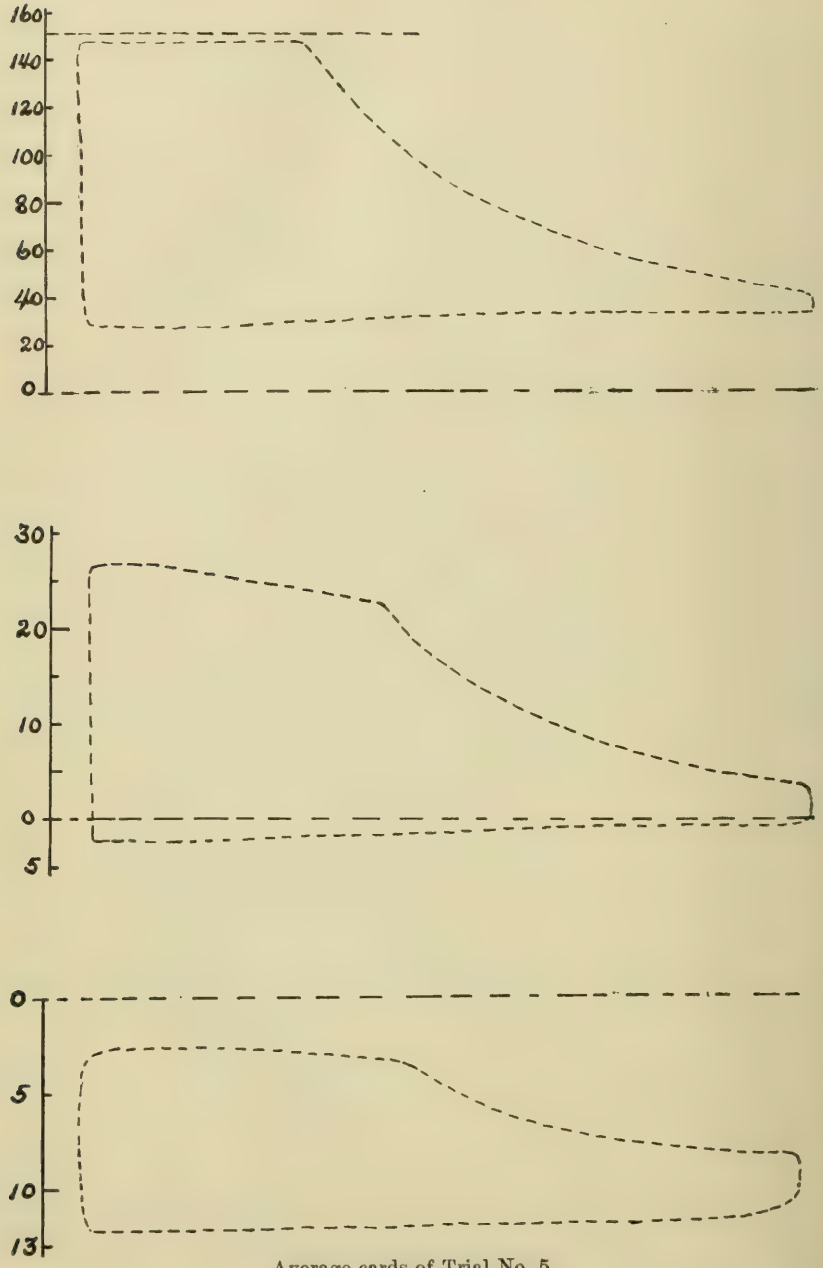
Average cards of Trial No. 4.

FIG. 443.



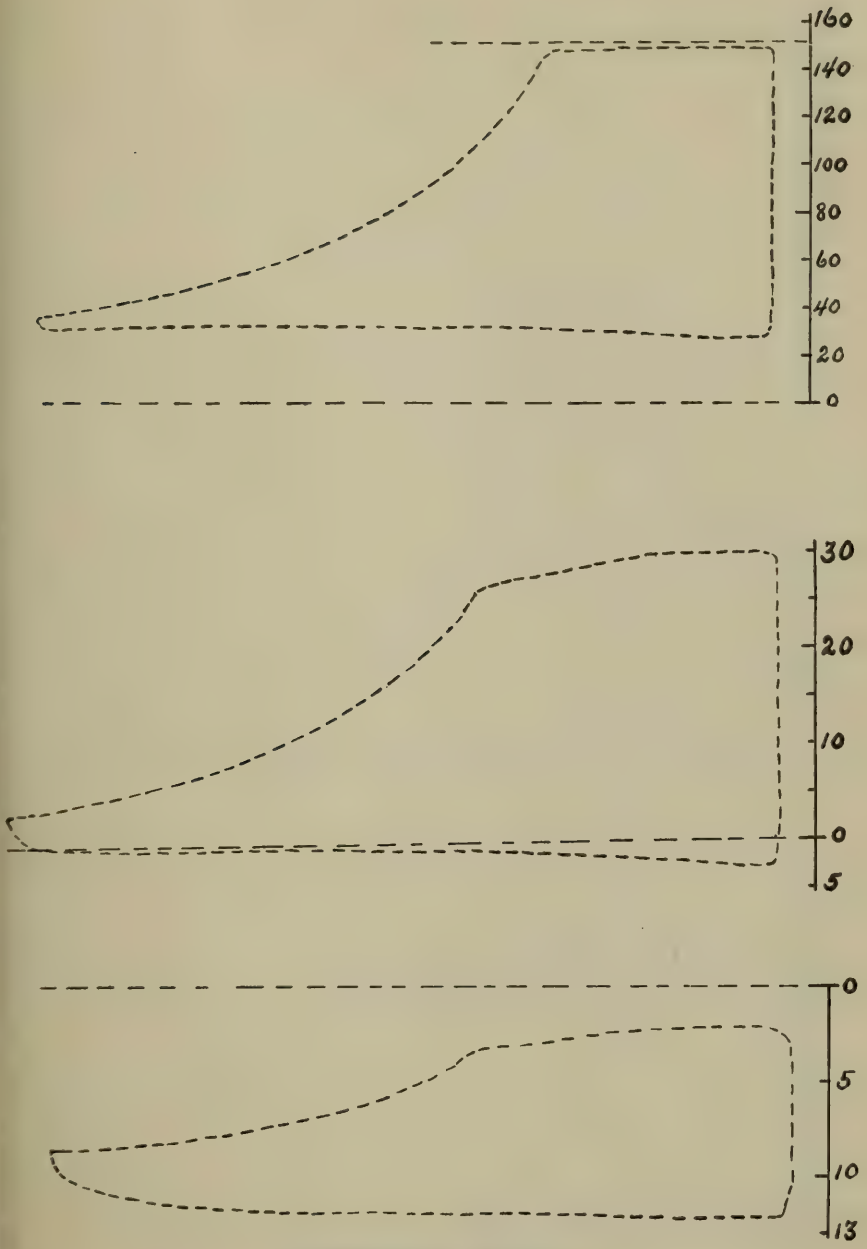
Average cards of Trial No. 4.

FIG. 444.



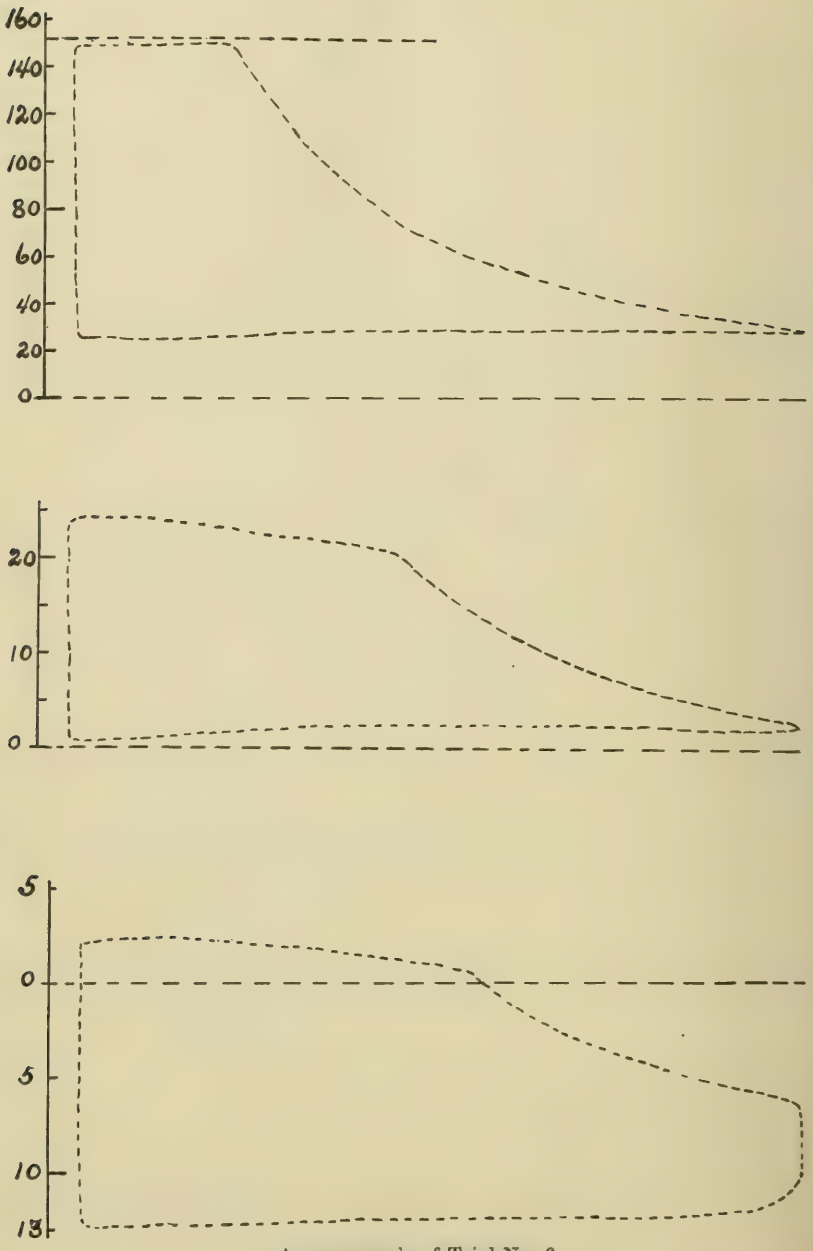
Average cards of Trial No. 5.

FIG. 445.



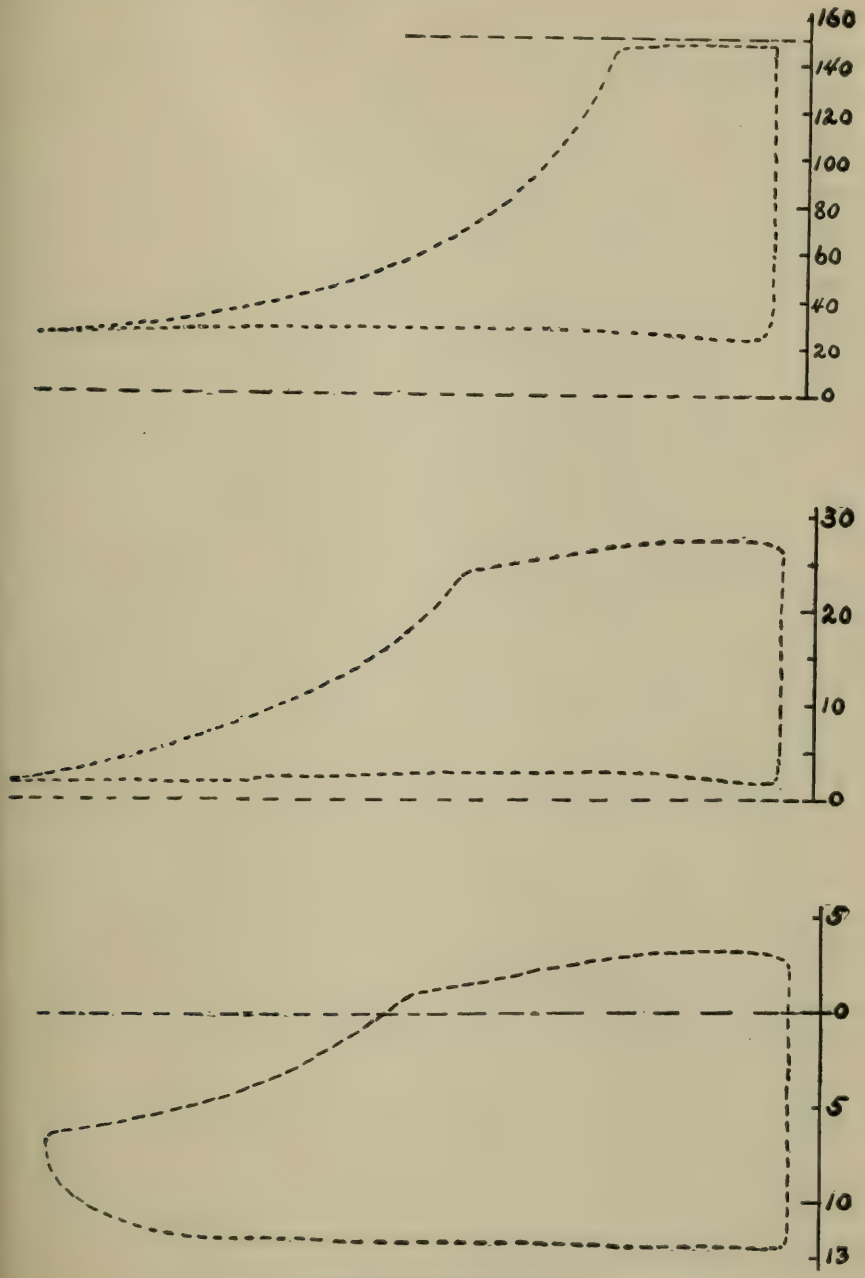
Average cards of Trial No. 5.

FIG. 446.



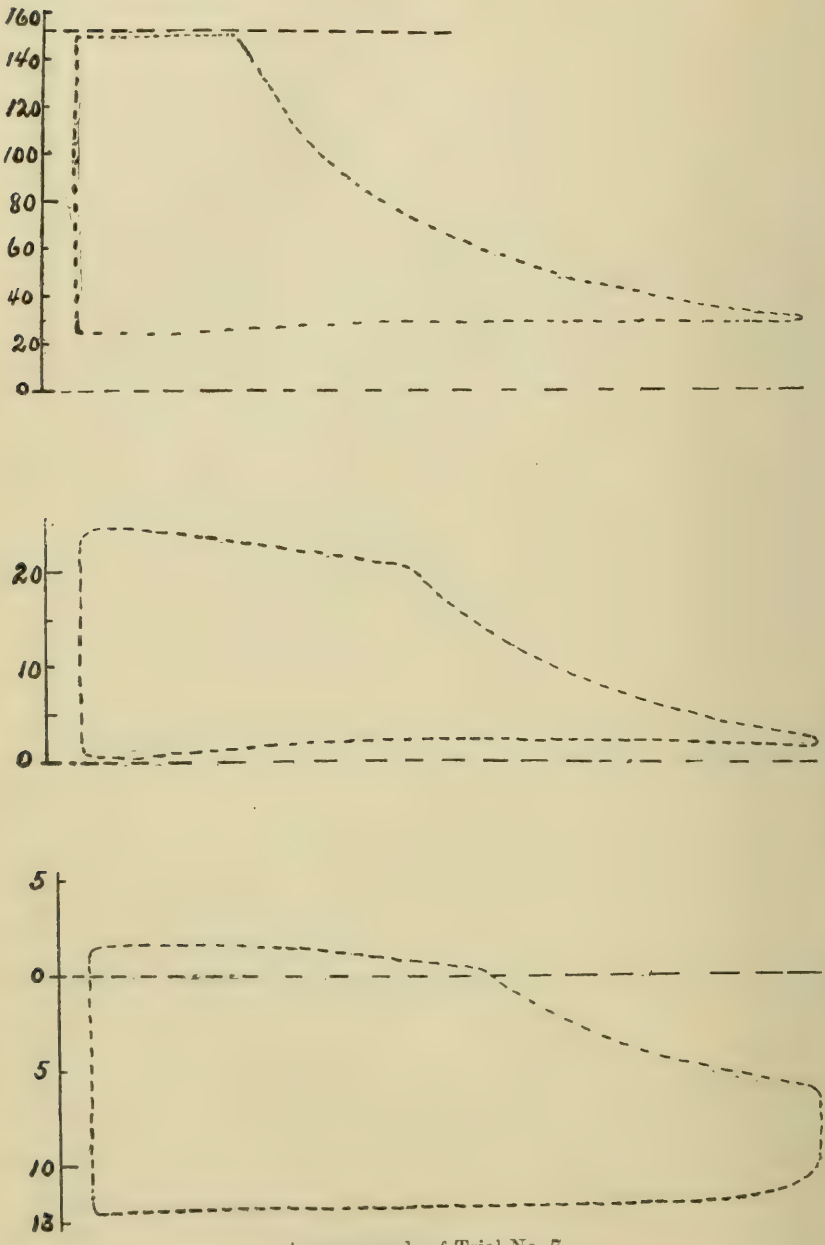
Average cards of Trial No. 6.

FIG. 447.



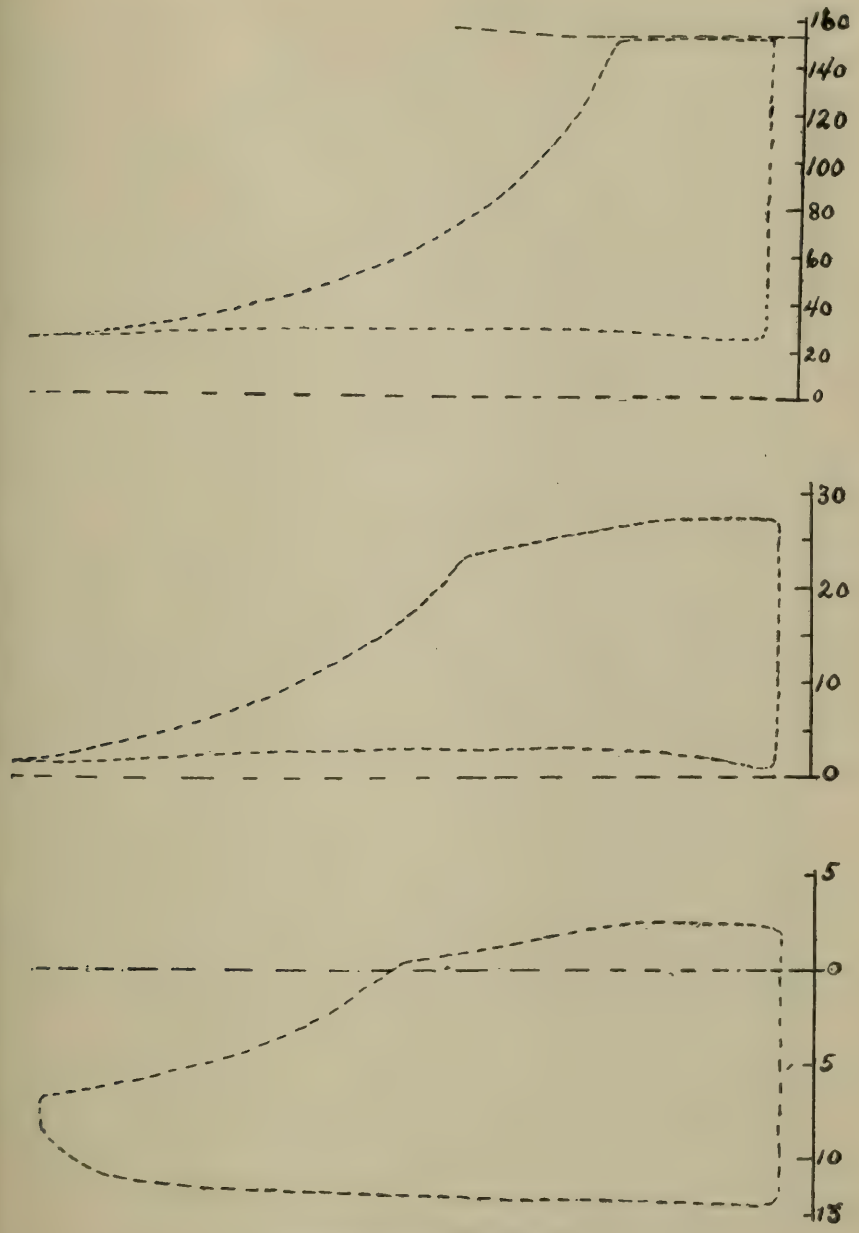
Average cards of Trial No. 6.

FIG. 448.



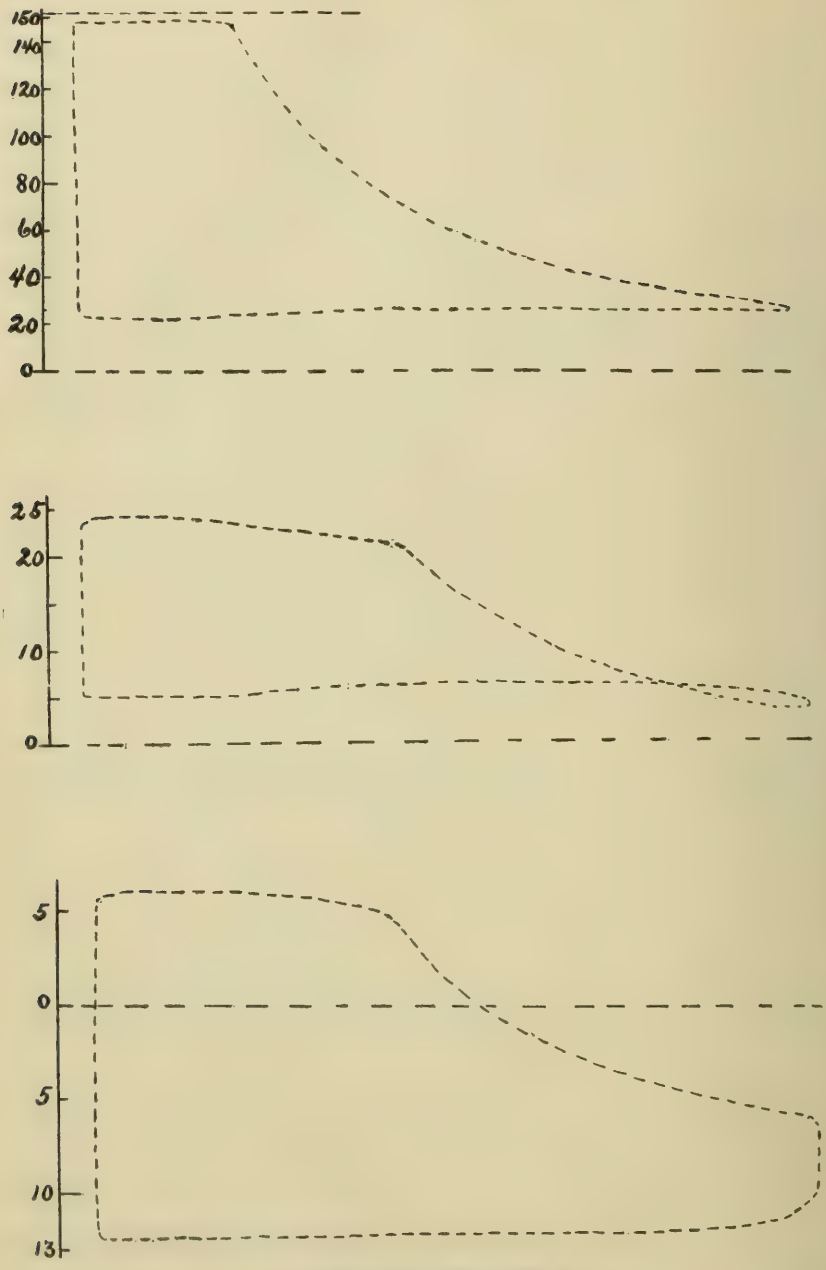
Average cards of Trial No. 7.

FIG. 449.



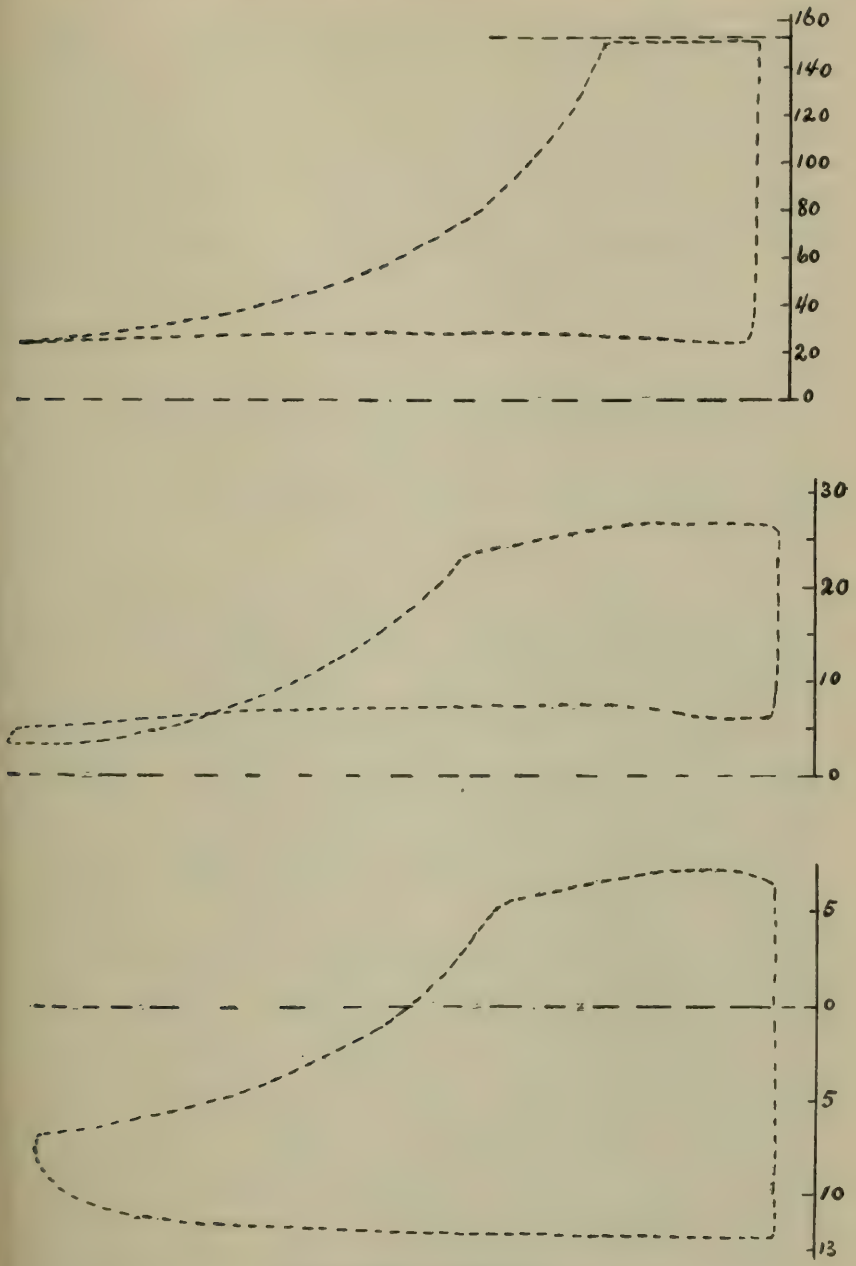
Average cards of Trial No. 7.

FIG. 450



Average cards of Trial No. 8.

Fig. 451.



Average cards of Trial No 8.

FIG. 452.

FIG. 453.

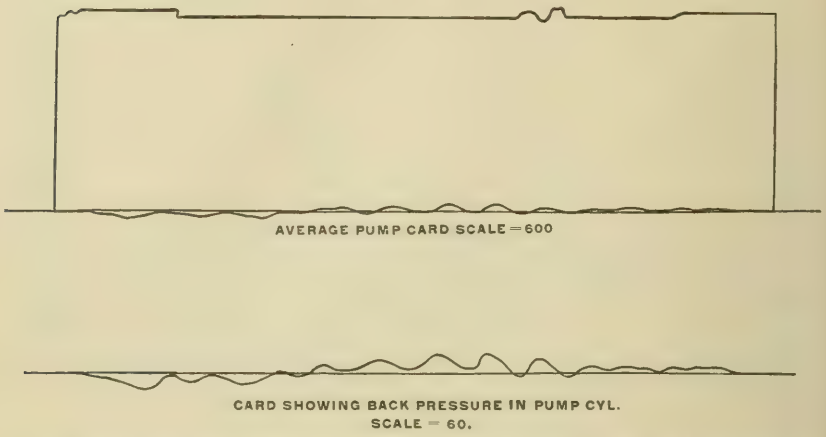


Fig. 453 shows the average pump card and a diagram of the back pressure in the pump cylinder.

DISCUSSION.

Mr. A. F. Hall. — On the twenty-eighth page of the paper (1366) referring to the S. S. *Iona*, Professor Denton writes: "The only jacketing was on the barrels of the high cylinder." This is misleading. On page 230 of the Excerpt Minutes of Proceedings of the Institution of Mechanical Engineers for April, 1891, Mr. Thomas Mudd says: "The high-pressure cylinder was placed in the middle, and it had three walls round it (Fig. 31, Plate 56). The innermost wall was, of course, the working barrel. The space between the inner and the middle wall formed a steam-jacket at full boiler pressure; this was the only jacket about the engines. The space between the middle and the outermost wall was partly the receiver between the first and second cylinders, but mainly the receiver between the second and third. The jacket therefore gave off heat inwards to the first cylinder, and outwards to the two receivers. Doubtless this double action of the jacket accounted for the large jacket condensation recorded in the report (page 210), namely 4.3% of the whole feed."

In a paper by Mr. Mudd, the designer, before the Institute of Naval Architects, March 20, 1891, page 12, particular attention is called to this feature; and the statement of Professor Denton is hardly proper without qualification, because the idea of enveloping the high-pressure steam-cylinder within the receivers of the other cylinders to reduce the loss of heat by radiation from

the steam when at its highest temperature is unique, and has, without doubt, much to do with the great economy of this engine. It is unfair to put this on the same footing with other engines not possessing this peculiarity. No correct inference can be drawn between engines of widely different construction as to their relative economy with and without jackets. The *Iona* has really reheaters for both the intermediate and low-pressure cylinders, and these cannot be separated or "cut out" for experimental work.

Again, on page 1367 of Professor Denton's paper, reference is made to Professor Schroeter's experiment on the triple expansion engine built by the Augsburg Maschinenfabrik with the Sulzer poppet valve-gear. It is absolutely impossible to make any reliable experiments on this engine, so far as the efficiency of steam-jackets is concerned; and it seems very strange that a man to whom the engineering profession looks for accurate work should make the remarks made by Professor Schroeter in his report on page 10 of the *Zeitschrift des Vereins deutscher Ingenieure*, January 4, 1890.

Professor Schroeter says: "A separation of the jacket of the intermediate-pressure cylinder from the first receiver, as well as a separation of the jacket of the low-pressure cylinder from the second receiver, was impossible, and was really of no importance."

Here was an engine having steam-jacketed receivers which were so connected with the jackets of their respective steam-cylinders that they could not be detached, and yet it was considered of no importance in studying the economy of steam-jackets.

Further, the high-pressure steam-cylinder received its steam from its own jacket, the steam to which jacket entered the bottom, and, consequently, carried in the current most of the steam condensed in the jacket of the cylinder, rendering it impossible to learn anything of the value of such a jacket. This could not be changed. The intermediate and low-pressure cylinders had independent jackets. All of the Sulzer engines, as built by the firm of Sulzer Brothers of Winterthur, have their jackets arranged like that of the high-pressure cylinder described above; that is, each steam-cylinder receives its supply from its jacket, the steam to the jacket *always* entering at the bottom.

The only thing which can be learned from experiments on such engines is, as to whether it is better to jacket the cylinder as followed by the Sulzer Brothers, or whether it is best to use independent jackets. But even then, if jacketed receivers or reheaters are used, they should be separable.

Little can be learned from the Augsburg engine, because it was neither one system nor the other, and, in addition, had jacketed receivers or reheaters, which could not be "cut out." It is certainly surprising that such things can be ignored by educated engineers. The experiment is of value from a commercial standpoint only, and not at all from a scientific one. The builders guaranteed an indicated horse-power per stipulated weight of steam per hour, and the determination of this was about the only thing of value. It is true that they determined what this *particular engine* would do when steam was and was not used in the *jackets* and *reheaters* combined, but very few inferences can be drawn from such experiments.

Many of our experimental data are so meagre that it is impossible to formulate any laws which will place the construction of the steam-engine on a scientific basis. It is of absolute importance in all experiments, not only that all data should be accurately determined and given, but that the construction of the machine itself should be exactly described.

Too much care cannot be exercised in experimental work, and the tendency to further one's hobbies should be strictly avoided. Let all the facts be so thoroughly given as to enable anyone to form his own independent views, for this is the only way in which experiments can have any scientific value.

The writer knows of no engine which has yet been constructed which is wholly suited to determine the relative merits of steam-jacketing and reheating. It must be obvious that an engine built with steam-jackets is not strictly comparable, when working without steam in the jackets, with one which is constructed without any jackets. These same remarks hold with reference to reheaters or any other deviation in the construction of the engines.

The day may come when our technical schools will be supplied with engines suitable for accurate scientific work, but the expense renders the thing almost impossible.

At present manufacturers are not interested in enlightening others in the construction of the steam-engine, and, as our tech-

nical schools depend largely upon public patronage for their support, great care must be exercised in expressing opinions which may affect the business interest of their patrons.

Mr. Frank H. Ball.—These comparisons, I think, are sometimes misleading. I refer particularly to the comparison made in this paper between the actual area of the combined cards and the area of a theoretical card constructed as shown. I knew of a test of a triple expansion engine where all the expansion curves reached the line of back pressure without free expansion, and all the compression curves were full compression curves, filling the clearance space to the initial pressure in each cylinder. Those cards grouped together in this manner would probably show 95% of the theoretical area. Yet that engine was using nearly double the steam that it ought to use. Now, the idea is just this: Everybody knows that it is not economy to expand to the return pressure in any of the cylinders, and some of us think it is not economy to compress to the initial pressure. Therefore if you are getting the highest economy in each cylinder, there will certainly be waste by free expansion in each cylinder and there will be consequent loss of area, although each cylinder may be developing the highest economy. Therefore I do not think it is best, except as a matter of curiosity, to compare engines on the basis of the ratio of the area of actual diagram to the theoretical. The highest economy in each cylinder is obtained when there is waste both at the exhaust opening and on the compression curve, and the most economical engine will not show the best ratio when compared in this manner.

Professor D. S. Jacobus.—I would like to say that it is perhaps simply the way in which I have presented this paper that has made this point misleading. In a table which is given in the paper, the various per cents. of steam accounted for are summed up. I have not copied the percentages of the jacket steam in the table given on the board. When the jackets are in action the effect is to increase the area; and when we include the jacket steam the apparent discrepancy will disappear. If you examine the table on page 1365 you will see that this is the fact.

Mr. Ball.—I merely spoke of the method as being misleading, where that alone was depended on in making comparisons between engines. It is always interesting to know what percentage of the theoretic area has been realized, while it does not necessarily give any satisfactory idea of the performance of the engine.

Professor G. I. Alden.—Referring to the interesting table on page 1365 I would like to ask Professor Jacobus whether the steam in the receivers which supply the low-pressure cylinders was superheated in any or all of these cases? I suppose that might have a very decided effect upon the efficiency of the engine; because, if we assume that the heat which is lost passes out at the exhaust port of the low-pressure cylinder, we should naturally expect that if the steam were dry at the end of expansion it would carry away much less heat from the cylinder than otherwise. I think that in the test of the Wheelock compound engine, the steam was superheated in the receiver as much as 30° or more. I did not know but Professor Jacobus could tell us about the quality of the steam in the receivers of the other engines compared.

Mr. Kent.—I would like to ask Professor Jacobus if that fourth line in Table IV. has any other interest than that of curiosity; because, under the head of "No jackets," the ratio of actual M. E. P. to theoretical is 20% less than in the case of the jackets, yet the increase of water consumption per horse-power is only 9% more, and in the case of the Sulzer engine, with lower ratio of M. E. P. than in the Laketon engine, there is still a greater economy. Another question is this: Will he give us the theory on which the Sulzer engine is based, and why it has so much greater economy than any other engine in his list? It is a matter of great importance, I think, that we should know the conditions which gave that engine its high economy.

Professor Jacobus.—I have already pointed out that the relation of the actual to the theoretical area is not the only factor governing the economy, but that the entire distribution of the steam, as given in the table, page 1365, must be considered in estimating the same. I have not gone into the details of the test of the Sulzer engine, and will therefore leave the question in regard to the jackets for Professor Denton to answer. I wish to make a remark in regard to what has been said about the gain due to the jackets being only 1½%. In no place in the paper can I see that the jackets are set down as producing only 1½%. On the contrary, on page 1359 we find it stated that:

"It is not to be concluded from these figures that if 20.5 expansions had been used without jackets, the water per horse-power would have been but 1.5% more without jackets than with the latter in use."

All the 1½% means is this: It is a fact that if we have a pump-

ing engine running against a given pressure, and shut off the steam from the jackets, we have to increase the cut-off in order to run at the same speed and power; and if we increase the cut-off beyond the point for the best economy, we tend to decrease the economy. The figure of 1½ is used only in connection with the statement of this fact. The only figure that is given for the effect of the jackets is 8.3, and this is the total effect of the jackets, no deduction being made for the difference of the cut-off.

Mr. Geo. H. Barrus.—Professor Denton's paper states that the Sulzer engine gave the best result yet attained. I should be sorry to have it go upon record that none of our American engines had given a higher performance than this Sulzer engine, and I would like to add to the paper the record of some tests which I believe to be authentic, which show that some of our engines have realized an economy of 11.68 lbs. of dry steam per indicated horse-power per hour. The Sulzer engine gives 12.73 lbs. I have seen records of a test made for the city of Chicago by Mr. Warrington and the R. W. Hunt Company, on the Fourteenth Street pumping engine, which was built by E. P. Allis & Co. of Milwaukee. The dry steam consumed per indicated horse-power per hour was 11.97 lbs. Another engine made by the same builders, which was tested by Professor Carpenter, gave a steam consumption of 11.68 lbs. Still another, made by the same builders for the West End Street Railway Company in Boston, the test being made by Mr. Mann for the West End Railway Company, and Mr. Larkin for the builders, gave a feed water consumption, wet steam, of 12.34 lbs. I have another test of a mill engine, built by the Corliss Company, which is now in use by the Richard Borden Manufacturing Company of Fall River, tested by myself, which gave a feed water consumption of 12.8 lbs. In this case the engine was not in the best condition, as the high pressure piston was leaking. These tests are summarized as follows:

1. Kind of engine, and maker	Pumping engine, E. P. Allis & Co.
2. Location	Chicago, 14th Street pumping station.
3. Capacity	15,000,000 each in 24 hours.
4. Number of engines	3.
5. Size of cylinders	27, 46, 70 inches.
6. Stroke	60 inches,
7. Test made by	James N. Warrington and the R. W. Hunt Co., for the city official test for the City of Chicago.
8. Duration	48 hours.

9. Boiler pressure .. ..120 lbs.
10. Revolutions per minute..... .16.3.
11. Indicated horse-power .....1,091.5 aggregate
12. Feed water per I. H. P.....12.13 per hour.
13. Moisture in steam.....1.32%.
14. Dry steam per I. H. P.....11.97 per hour.
15. Duty on 1,000,000 heat units .....134,643,030 ft. lbs.

1. Kind of engine, and maker.....Pumping engine, E. P. Allis & Co.
2. Location.....Milwaukee, North Point pumping station.
3. Capacity..... ....18,000,000 gallons.
4. Number of engines... .....1.
5. Size of cylinders ....28, 48, 74 inches.
6. Stroke..... .....60 inches.
7. Test made by ....Prof. R. C. Carpenter and students of Cornell University.
8. Duration .....24 hours.
9. Boiler pressure .....121.4 lbs.
10. Revolutions per minute.....20.3.
11. Indicated horse-power.....573.9.
12. Feed water per I. H. P.....11.82 per hour.
13. Moisture in steam.....1.05%.
14. Dry steam per I. H. P.....11.68 per hour.
15. Duty on 1,000,000 heat units .....137,656,000 ft. lbs.

1. Kind of engine, and maker.....Electric Railway Service, E. P. Allis & Co.
2. Location.....West End St. Ry. Co., Boston, Mass.
3. Capacity.....1,200 H.-P.
4. Number of engines.....1.
5. Size of cylinders .....23, 36, 52 inches.
6. Stroke.....48.
7. Test made by. .....A. S. Mann, for the West End St. Ry. Co.; F. A. Larkin, for the Edward P. Allis Co.
8. Duration.....5 hours.
9. Boiler pressure.....157.5 lbs.
10. Revolutions per minute..... ....69.6.
11. Indicated horse-power.....973.85 eng.
    8.25 cond.
    ———
    982.1 total.
12. Feed water per I. H. P.....12.34 per hour.

1. Kind of engine, and maker.....Mill service, The Corliss Steam Engine Co.
2. Location .....Richard Borden Mfg. Co., Fall River, Mass.
3. Capacity..... .....1,000 H.-P.
4. Number of engines.....1.
5. Size of cylinders. .....20, 34, and two 36 inches.

6. Stroke.....60 inches.
7. Test made by.....Geo. H. Barrus.
8. Duration.....11 hours.
9. Boiler pressure.....151 lbs.
10. Revolutions per minute.....65.2.
11. Indicated horse-power.....996.8.
12. Feed water per I. H. P.....12.8 per hour.
13. Moisture in steam.....Superheated 39°.
14. Dry steam per I. H. P.....12.8 per hour.
15.
16. High pressure piston on this test was found to leak.

*Prof. J. E. Denton.**—Referring to Mr. Ball's remarks: It is true that the realization of a large percentage of the area of the "ideal" card *a b f g h* in the sum of the areas of the combined diagrams may not imply high economy. This is shown clearly by the analysis of the Lawrence compound pump, in which the large percentage of the "ideal" card realized by the actual cards is accompanied by an excessive cylinder condensation and large jacket consumption, making the economy much less than that of engines having a perfect steam distribution. The slow speed of this engine, and the large range of temperature in the high cylinder, permitted a large degree of reëvaporation during expansion in the high cylinder, and thereby the card area was abnormally increased.

The card area must be considered in conjunction with the ratio of expansion, the cylinder condensation during admission to high cylinder, and the jacket consumption, in order to define the economy. The latter three elements vary independently of the losses of card area due to "drop" of pressure at release, and between cylinders, and imperfect vacuum. Deficiency of card area may, therefore, be neutralized by small cylinder condensation and jacket consumption, the erratic variations of which may also compensate for large differences in the ratio of expansion. For example, the Sulzer engine realizes 85% of the "ideal" card, but shows a greater economy than the Wheelock with 94% of card area and greater ratio of expansion.

The Milwaukee pumping engine, which has recently accomplished the remarkable economy of 11.8 lbs. of water per hour per horse-power, realizes but 82% of its "ideal" card area, and its ratio of expansion is only 18.4 with 120 lbs. boiler pressure.

* Author's Closure under the Rules.

The jacket steam consumption is, however, only 10.7%, and the cylinder condensation at cut-off in the high cylinder only 2.6% of the steam entering the high cylinder, as compared to 31% for the sum of these two elements in the Sulzer engine. The latter's greater ratio of expansion and higher per cent. of card area are, therefore, unable to compete with the favorable conditions of the Milwaukee engine regarding cylinder condensation and jacket steam consumption.

So far as the card area may be increased, however, by reduction of "drop," or the use of a more perfect vacuum, the higher the percentage of the "ideal" card area realized in the combined cards, the greater the economy.

The above explanations, I think, also answer Mr. Kent's questions regarding the cause of the superior economy of the Sulzer engine.

Mr. Hall's reminder that the jacket of the high cylinder of the *Iona* acted partly as a reheater for the intermediate and low receivers is a pertinent one. While I do not believe the action of the jacket upon the receivers sensibly increased the economy, the peculiarity of the arrangement should be noted. In describing the engine as having a jacket on the high cylinder only, I copied the language of the Report of the British Marine Trial Committee. I have now added a foot-note to the paper, calling attention to the peculiar arrangement of the jacket and the receivers.

This speaker's remarks about the arrangement of jackets on the Sulzer engine indicate some misunderstanding, as the jackets of the engine whose performance is under notice did not serve as steam-chests to the respective cylinders, except in the case of the high cylinder.

The intermediate and low jackets and receivers were connected only with the boiler, and were supplied with steam at boiler pressure.

The facts available regarding steam-engine economy do not show that the use of all the jackets as steam-chests sensibly reduces the economy. The jackets on both cylinders of the first Pawtucket compound pumping engine were isolated chambers connected only with the boiler. The water consumption, with full boiler pressure, and the corresponding temperature in the jackets, with all air eliminated from the latter,* was the minimum

* *Vide* tests by Jacobus and Kent, *Transactions* A. S. M. E., Vol. XI.

afforded by any compound engine, namely 13.7 lbs. per hour per indicated horse-power.

The second Pawtucket compound was similar in its proportions and steam distribution, but the *jackets acted as steam-chests on both cylinders*. A careful test of this engine by Professor Jacobus gave *slightly better economy than the engine with isolated jackets*. The principal results, hitherto unpublished, were as follows:

Date of trial	Nov. 6, 1890.
Duration of trial	11 hours.
Indicated horse-power	313.39.
Revolutions per minute	47.8.
Feed water per hour per indicated horse-power	13.47.
Quality of steam	Dry to 10° superheated.
Average boiler pressure above atmosphere	124.6 lbs.
Vacuum	27.5 inches.
Cut-off high cylinder	0.23.
Ratio of expansion	16.0.
Temperature feed water	113.2°.
" hot well	96.5.

DIMENSIONS OF ENGINE.

Diameter of high cylinder	20 inches.
" " low "	40 "
" " piston rods	4 "

Since the completion of this paper the results of a test of a triple-expansion engine, with jackets as steam-chests, have been made public, and they show a water consumption of 12.8 lbs. per hour per indicated horse-power. (See Mr. Barrus' statement above of results of test of engine at Richard Borden Mill.) It appears, therefore, that the quoted opinion of Prof. Schroeter regarding the unimportance of such a detail of jacket arrangement as is referred to by the speaker, may be well grounded, by virtue of some of his extensive experience with the performance of engines other than the one under discussion; and inasmuch as the object of Prof. Schroeter's test of this engine was not to investigate the value of jackets, but simply to record the accomplishment of the minimum economy which up to that date had been attained by the triple-expansion principle, the impeachment of the scientific character of his methods by the speaker is rather gratuitous.

In my treatment of the gain due to the use of jackets I think

the language used on page 1359 makes sufficiently clear the hypothetical character of the deduction, that all but 1.5% of the gain due to the jackets is ascribable to the greater range of expansion used with the jackets. While, however, the method by which this figure of 1.5% is derived is a logical one, the figure is in error, because the water per hour per horse-power, given at 14 99 lbs. for the test without jackets (Table II.), should have been 14.09 lbs. (See foot-note, Table II.) This fact makes the actual gain due to the use of jackets 1.9%, instead of 8.3%, and the value of $100 - S$ (Tables III. and IV.) becomes 84%. The theoretical deductions, page 21, should therefore be as follows:

If in the test without jackets the ratio of expansion was 20.5, as in the tests with jackets, the theoretical water per hour per horse-power (W, Table IV.) would be reduced $8.74 - 8.18 = 0.56$ lbs. If, then, the percentage of mean effective pressure of the "ideal" card realized (F, Table IV.) and the per cent. of water unaccounted for at cut-off of high card ($100 - S$, Table IV.) were the same, with 20.5 expansions without jackets, as for the test without jackets at 15 expansions, the water per horse-power would be that for the latter, reduced by $\frac{0.56}{0.86 \times 0.74} = 0.88$ lbs., making the water per horse-power, with jackets at 20.5 expansions, $14\,09 - 0.88 = 13.21$ lbs., or 4.5% less than with the jackets in use.

It is not to be concluded from this deduction that if 20.5 expansions had been used without jackets, the water per horse-power would have been less than with jackets, as the supposition made regarding equal values of F and of $100 - S$ would not have been realized. Both these values would undoubtedly be increased at 20.5 expansions, and probably to such an extent as to make the loss due to jackets much greater than the 1.9% here reported.

So small a gain due to the jackets is a surprise to me, but it presents no apparent inconsistency compared with the other tests, as it allows for a large loss of card area from "drop," and for considerably more cylinder condensation during admission to high cylinder than occurs with the same range of temperature in Test No. 4 with the jackets in use.

It was pertinently pointed out during the discussion that, if the jacket-drains were mixed with the feed-water, the gain in *fuel* consumption, by the use of a jacket, is shown only by comparison of the heat units per horse-power, which in this case makes about

3.5% more gain for the jacket than is shown by comparing the water consumption figures.

In computing the performance with reference to fuel consumption (see duty calculations, page 1349), I have used the heat unit basis, but the discussion regarding jacket gain was confined to the consideration of water consumption per horse-power. I have now, however, added the heat unit figures in foot-notes.

DLIV.*

THE REFRIGERATING MACHINE OF TO-DAY.

BY C. LINDE, MUNICH, GERMANY.

On reviewing the development of the refrigerating machine within the last ten years, a notable feature will be found to be the increase in their number. Considerable as was the number of cooling machines in use in 1883, it represents only a relatively modest figure when compared with the imposing number of machines set to work during the decade now expired. Entire fields of industry have been laid open to the employment of refrigeration, and, apart from technical electricity, hardly any other branch of modern industry is able to show such rapid development. There can be no doubt that during this time there have been noteworthy improvements in the construction of refrigerating machinery and important novelties in the methods of applying cold for the most diversified purposes. But no methods new in principle have appeared, and also no striking discoveries or inventions which might have furnished new lines for the production of cold. We stand in a time of elaboration of the foundations laid in previous decades.

The cold-air and absorption machines having thus been in existence for more than three decades, the ammonia-compression machine during two, and the youngest member of the series of industrially important machines—the carbonic-acid machine—being beyond the first decade since its introduction,† it will not be questioned that the initial development of these machines has been attained long ago, as they have been executed partly in thousands, or at least in hundreds, of instances and thus have proved themselves thoroughly serviceable. Opportunities cannot have been wanting for forming an opinion con-

* Presented at the Chicago Meeting (August, 1893) of the American Society of Mechanical Engineers and forming part of Volume XIV. of the *Transactions*.

† The carbonic-acid ice-making machine constructed for F. Krupp, at Essen, in 1882 by the Maschinenfabrik Augsburg on lines furnished by the author, will have to be considered as the first installation of this kind.

cerning the advantages and drawbacks of these various systems of machines. But alone the circumstance that they all play a part in the market of to-day proves the existing differences of opinion concerning these advantages and disadvantages, and that the drawbacks apparent in one direction are accompanied by advantages in other respects. Thus an attempt to challenge a final decision on the respective merits is well-nigh impossible.

EFFICIENCY.

Production and Consumption.

More favorable prospects, however, may be expected from the solution of the problem when it is so chosen that it is limited to certain questions, permitting a precise and analytically defined expression; for instance, the question of efficiency is such a one—that is to say, the relation between the quantity of cold produced and the expenditure of mechanical work (or heat) and of cooling water.

None of the classes of refrigerating machines which have been mentioned are to-day individual property. Any manufacturer is at liberty to construct absorption machines or to adopt sulphurous acid, ammonia, or carbonic acid for a compression machine. A correct answer to the question of the influence which various methods of working and the selection of the working agents exert upon the efficiency may consequently be presumed to meet with universal interest.

If it be attempted in the following lines to raise a discussion on this subject, such an endeavor is made with the knowledge that also this question will not find a final answer in its entire extent, but within certain limits only.

It may be preassumed as generally acknowledged that the cold air machine in point of efficiency is considerably surpassed by other groups.* The two following questions will, however, be replied to variously: What is the relation between the absorption and the compression cycle, and what influence upon a compression machine is exerted by the use of sulphurous acid, of ammonia, or of carbonic acid?

* For confirmation the following results obtained from various cold-air ma-

ABSORPTION AND COMPRESSION.

Two methods present themselves for the treatment of this question, the one consisting of theoretical calculation based on thermodynamics, and the other on experimental tests upon machines actually constructed.

Thermodynamics enable us to calculate for the various systems of machines with full certainty the *maximum efficiency* which can be reached by a certain definite working process. Experimental investigation affords, on the other hand, the only reliable proof in how far the *actual efficiency* falls short of this maximum for every single machine system. For the compression machine it is especially possible to express this theoretical maximum by the familiar * formula:

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chines are appended, which should be compared with the corresponding column of Table I., given farther on:

ACTUAL PERFORMANCE OF COLD-AIR MACHINES.

System	Bell-Coleman.	Lightfoot.	Haslam.
Test No.	1	2	3
Diameter of compression cylinder	28″	27″ single-acting	25½″ two-cylinder
Diameter of expansion cylinder	21″	22″	19¼″ two-cylinder
Diameter of steam cylinder	21″	.....	20″ H. P. 31½″ L. P.
Stroke of all cylinders	24″	18″	36″
Revolutions per minute	63.2	62	72
Air-pressure in receiver lbs. (absolute)	61	65	64
Temperature of air entering the compression cyl.	65½° F.	52° F.	.....
Temperature of air after expansion	— 52.6° F.	— 82° F.	— 85° F.
I. H. P. in compression cylinder	124.5	43.1	346.4
I. H. P. in expansion cylinder	58.5	28.0	176.2
I. H. P. in steam cylinder	84.4	24.6	332.7
B. T. U. abstracted per hour and I. H. P. of steam cylinder at 20° F	668	1,554	954

The figures for Test No. 1 have been observed and published by Professor Schröter (*Untersuchungen an Kältemaschinen verschiedener Systeme*, Munich, 1887); those for No. 2 are published in minutes *Proc. Inst. Mech. Eng.*, London, 1881. The data for trial No. 3 are taken from a paper read last year before the Manchester Society of Engineers.

* It should be stated that also in this last decade individual attempts have not been wanting which denied the general validity of the "second law" of thermodynamics on which this equation is founded, or which endeavored to interpret this law in a misleading manner. The "second law" is, however, so firmly upheld in its truth by all experts, that the refutation actually established by experiment was hardly necessary to repel such efforts.

$$\frac{Q}{AL} = \frac{T}{T_c - T} \quad \ldots \ldots \ldots \quad (1)^*$$

For the comparison of efficiency between a compression and an absorption machine (which latter is not acted upon by external mechanical work, but by heat), it is necessary to place alongside the absorption machine a combination of a compression machine and a heat-engine (for instance, a steam-engine). If u be the ratio between the equivalent of mechanical work AL and the quantity of heat Q', which must be imparted to the motor to produce the work L, we write:

$$\frac{AL}{Q'} = u, \text{ and obtain:}$$

$$\frac{Q'}{Q} = \frac{T_c - T}{uT} \quad \ldots \ldots \ldots \quad (2)$$

It follows, as a result, that the expenditure of heat Q' necessary for the production of the quantity of cold Q in a compression machine will be the smaller, the smaller the difference of temperature $T_c - T$ will be, and that both values possess the limiting value 0.

How far does this apply to the absorption machine? Let the working process be assumed to be performed without any losses, and let the cycle of 1 lb. of ammonia† be considered, then there will be produced in the refrigerator a quantity of cold Q equal to the latent heat r less the heat of liquid $(q_c - q)$ brought by the ammonia from the condenser into the refrigerator. The heat Q' to be supplied to the still is composed of the heat of absorption $s_c = r_c + a_c$ and the specific heat of the ammonia which has been heated from the absorber temperature (t_a) to the temperature of the still (t').

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* The formula expresses: The theoretical maximum of heat abstracted (produced cold) stands to the thermal equivalent of the mechanical work to be expended in the same ratio as the (absolute) temperature for the heat-abstraction bears to the difference between this temperature and the temperature for the heat-rejection.

† Only such absorption machines will be here considered, which work with ammonia and water, as other absorption machines do not to-day possess any practical importance.

We find, therefore (neglecting the work of the liquor-pump and any water which may participate in the cycle):*

$$\frac{Q'}{Q} = \frac{r_c + a_c + c(t' - t_c)}{r - (q_c - q)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If we allow the range of temperatures to be reduced to an infinitely small amount in order to obtain Q' as small as possible as compared with Q, we find as limiting value,

$$\left(\frac{Q'}{Q}\right)_0 = \frac{r + a}{r} > 1.$$

In contrast to the limiting value 0 for compression machines we find here a value > 1, from which results that, at any rate between certain limits of temperatures, the compression principle will hold out indications of a higher efficiency than the absorption principle.

In how far this really applies for the *actual efficiency*, can only be determined from the results of quite reliable tests and measurements. It will be especially a case of proving whether the *actual efficiencies* hitherto obtained from compression machines do not already within certain limits surpass the *theoretical maximum limit* of the efficiency of the absorption machines.

It is now intended to be demonstrated that such is the case.

The most favorable results known to the author of such trials (the carrying out of which gives full assurance of reliability) are here appended; they belong to an ammonia-compression machine.†

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* Thus we consider $t_a = t_c$.

† The trials here referred to were carried out in the month of May of the present year in the "Testing Station for Refrigerating Machines" of the "Polytechnische Verein" at Munich by a committee of this Society. This committee is composed of five professors of mechanical engineering (holding chairs in five of the German Technical High Schools, one member being Dr. Zeuner), of two professors of physical science, one chemist, and others. The director and reporter is Professor Schröter, of Munich. It is a matter of regret that hitherto manufacturers of ammonia-compression machines only have availed themselves of the opportunity of an exact investigation of their apparatus; there have been tested several ammonia-compression machines and one sulphurous-acid machine.

TABLE I.

AMMONIA-COMPRESSION MACHINE.

*Actual results obtained at the Munich tests.**

No. of Test	1	2	3	4	5
Temperature of refrigerated brine,† Inlet, deg. Fahr.	43.194	28.344	13.874	−0.279	28.251
Temperature of refrigerated brine,† Outlet, t deg. Fahr.	37.054	22.885	8.719	−5.879	23.072
Specific heat of brine (per unit of volume)	0.8608	0.8508	0.8427	0.8374	0.8508
Quantity of brine circulated per hour, cu. ft.	1,039.38	908.84	615.36	414.98	800.93
Cold produced, B. T. U. per hour	342,909	263,950	166,879	121,474	220,284
Temperature of cooling water in condenser. Inlet, deg. Fahr	48.832	49.476	49.104	49.098	49.235
Temperature of cooling water in condenser. Outlet, t_c deg. Fahr	66.724	68.013	67.104	67.267	93.366
Quantity of cooling water per hour in cu. ft.	338.76	260.83	187.40	139.99	97.76
Heat eliminated by condenser, B. T. U. per hr.	378,358	301,404	210,570	158,926	271,134
I. H. P. in compressor-cylinder	13.82	14.29	13.84	11.98	19.75
I. H. P. in steam-engine cylinder	15.80	16.47	15.45	14.24	21.61
Consumption of steam per hour in lbs.	311.51	335.98	306.81	278.79	430.14
Cold produced per hour, B. T. U. Per I. H. P. in comp.-cyl	24,813	18,471	12,058	10,140	11,151
Cold produced per hour, B. T. U. Per I. H. P. in steam-cyl	21,703	16,026	10,841	8,530	10,194
Cold produced per hour, B. T. U. Per lb. of steam.	1,100.8	785.6	543.9	435.82	512.12
$\eta = \frac{Q}{AL_e} \times \frac{t_c - t}{460 + t}$ ‡	0.548	0.635	0.569	0.585	0.616
$\frac{Q}{Q}$ = cold produced ÷ heat expended	0.970	0.708	0.490	0.393	0.462

The motor was here a small single-cylinder condensing steam-engine (diameter, 11″, stroke, 27½″), for which the mean value of u was determined at $u = 0.114$.

For a more powerful compound steam-engine with a value of $u = 0.158$, corresponding to modern attainments in steam-engine practice, *i. e.*, 14 lbs. steam per hour and I. H. P., the efficiencies will result:

TABLE I*a*.

AMMONIA-COMPRESSION MACHINE.

Actual Performance, assuming a Compound Steam-engine as Motor.

No. of Test	1	2	3	4	5
$\frac{Q}{Q}$ = cold produced ÷ heat expended	1.362	1.001	0.678	0.533	0.637

* *Vide Bayerisches Industrie und Gewerbeblatt*, Munich, 1893.

† The specific gravity of the brine (a solution of chloride of calcium in water) was 1.249 at 63.5° Fahr. for all tests.

‡ In the calculation of η, *i.e.*, the ratio between the actual efficiency $\frac{Q}{AL_e}$ and the theoretical maximum efficiency $\frac{Q}{AL} = \frac{460 + t}{t_c - t}$, the actual work expended upon the machine (L_e) has been taken equal to the indicated work in steam-engine reduced by 1.2 I. H. P., *i.e.*, the indicated work of steam-engine running empty (without compressor).

To enable a comparison of these values with the theoretical maximum efficiency of an absorption machine, we have to substitute in equation (3) the values corresponding to the temperatures between which the tests Nos. 1–5 have been carried out.

In this manner the following maximum values * for $\frac{Q}{Q'}$ are obtained (*i.e.*, for the performance of an absorption machine without reference to any losses, also not to the work of the liquor pump and of water entrained by the ammonia) :

TABLE II.

AMMONIA-ABSORPTION MACHINE.

No. of Corresponding (Munich) Test	1	2	3	4	5
Corresponding temperature t deg. Fahr.....	37	23	8	−6	23
Corresponding temperature t_c.....	68	68	68	68	95
Theoretical maximum efficiency $\frac{Q}{Q'}$ = ...	0.534	0.527	0.522	0.516	0.493

A comparison of the Tables I. and I*a* with Table II. demonstrates :

(1) The actual efficiency of the ammonia-compression machine investigated at Munich is, for the Tests Nos. 1 and 2, higher than the theoretical efficiency obtainable from an absorption machine working without loss.

(2) The actual efficiency of the ammonia-compression machine is also higher in Trials Nos. 3, 4 and 5, if a compound steam-engine be assumed as motor, the steam consumption of which amounts to 14 lbs. of steam per I. H. P. per hour.†

* In conformity with the conclusions arrived at by Ledoux and by Denton (*Trans. Amer. Soc. Mech. Engrs.*, Vol. X.), the heat of absorption is here taken uniformly at 925.7 B. T. U.

† As regards the actual efficiency of the absorption machine, it appears, according to the information at present available, not to exceed 50% of the maximum efficiency. Professor Schröter (*Untersuchungen an Kältemaschinen*, Munich, 1887) has found for $t = 12°$ Fahr. and an inlet temperature of the cooling water of about 50° Fahr. in testing three different absorption machines (neglecting work of liquor pumps), $\frac{Q}{Q'} = 0.17$, 0.23, and 0.25 ; if the steam necessary to work the pumps and agitators be included, about 0.10, 0.145, and 0.15 respectively.

F. E. Denton (*Trans. Amer. Soc. of Mech. Eng.*, Vol. X., page 792) has found for $t = 16°$ Fahr. an initial temperature of the cooling water of 54° Fahr., and an outlet temperature of 80° Fahr. : $\frac{Q}{Q'} = 0.30$ without steam for liquor pump, and 0.26 including this steam.

For a better survey of these results the following Table III. has been compiled, giving values for the respective ratios of actual efficiencies of the compression machine to the theoretical maximum of efficiency of the absorption machine:

TABLE III.

No. of Test		1	2	3	4	5
Temperature of cooling water leaving condenser, deg. Fahr.		68	68	68	68	95
Final temperature of refrigerated brine, deg. Fahr.		37	23	8	−6	23
Actual efficiency of compression machine ÷ theoretical maximum efficiency of absorption machine.	According to Table I	1.816	1.398	0.939	0.762	0.937
	According to Table Iα	2.551	1.899	1.299	1.033	1.292

Although it may be gathered from the foregoing as being exceedingly probable that, for all temperatures important for practice, the actual efficiency of ammonia-compression machines of good construction will be superior to that of absorption machines, it will only be held that the following has been proved:

With ammonia-compression machines actual efficiencies have been obtained which, within temperature ranges $t_c - t \leqq 75°$ *Fahr.* [*that is, the difference of temperatures between the outgoing cooling water* (t_c) *and the final brine temperature* (t)], *surpass the efficiencies obtainable by absorption machines, even if it were possible for them to perform the cycle without loss of any kind.*

Within these ranges of temperature no alterations or improvements of the absorption machine will enable it to produce the same quantities of cold with an expenditure of heat sufficing for an ammonia-compression machine like that recently tested at Munich.

SULPHUROUS ACID, AMMONIA, OR CARBONIC ACID?

The theoretical maximum of efficiency for a compression machine is (according to formula 1) independent of the working fluid. Hence any differences in this efficiency observable in the action of different fluids, can only be attributed to losses of work and heat.

EXPANSION FROM CONDENSER TO REFRIGERATOR.

Formula 1 refers to the "complete" (Carnot) cycle, which is composed of two isothermals and two adiabatics.

It is, however, well known that the compressors perform only three of these four "perfect" processes, while for the fourth process, *i.e.*, the adiabatical expansion from the condenser temperature to the refrigerator temperature, a direct injection of the liquid is substituted whereby heat of liquid is imparted to the refrigerator, so that per pound of the fluid only the heat $r-(q_c-q)$ is abstracted from the body to be cooled. It is evident that the loss thus caused will be the greater, the greater the liquid heat of the working substance will be relatively to its latent heat. Table IV. demonstrates in this respect the behavior of the three industrially important fluids of the present day.

TABLE IV.

t_c* deg. Fahr.	t deg. Fahr.	Sulphurous Acid.			Ammonia.			Carbonic Acid.		
		Latent heat.† r	Heat of liquid. q_c-q	Loss in efficiency. ξ	Latent heat. r	Heat of liquid. q_c-q	Loss in efficiency. ξ	Latent heat. r	Heat of liquid. q_c-q	Loss in efficiency. ξ
50	32	164.16	7.32	0.0171	566.75	18.98	0.0181	102.35	17 60	0.0983
	14	168.19	13.49	.0411	577.47	36.45	.0349	115.70	32.09	.1813
	−4	171.00	18.50	.0618	586.51	52.41	.0507	126.79	44.51	.2426
68	32	164.16	15.79	.0522	566.75	39.46	.0387	102.35	40.86	.2843
	14	168.19	21.96	.0758	577.47	56.93	.0565	115.70	55.35	.3646
	−4	171.00	26.97	.0972	586.51	72.89	.0735	126.79	67.77	.4252
86	32	164.16	25.41	.0888	566.75	61.45	.0652	102.35	84.44	.7834
	14	168.19	31.58	.1146	577.47	78.92	.0813	115.70	98.93	.8311
	−4	171.00	42.76	.1380	586.51	94.88	.0993	126.79	111.35	.8662

Every third column indicates the loss in efficiency ξ,‡ *i.e.*, of that part of the refrigerating effect due to the imperfection of the working process referred to, on the assumption that the compressor will aspirate dry vapor possessing the temperature of the refrigerator.

* Hereby it is assumed that the fluid will reach the expansion valve possessing the temperature t_c.

† The figures for latent heat and heat of liquid are taken from Zenner's tables for sulphurous acid and ammonia, and from Schroeter's table for carbonic acid.

‡ Calculated from *Technische Thermodynamik*, by Dr. G. Zeuner, p. 462.

Note.—The values G of the losses are calculated according to Zeuner's equation (24):

$$AL = G\,(q_c - q + xr_c - xr + Ab\,[p_c - p]);$$

but in this calculation that part of the equation ($Ab\,[p_c-p]$) having reference to the volume of the liquid has been left out. In the case of sulphurous acid and ammonia this part is in reality very small, but in the case of carbonic acid it exercises such a remarkable influence—as has been proved by later calculation

The unfavorable relation of the heat of liquid to latent heat for carbonic acid explains why the efficiency of the carbonic-acid machine falls behind that of the ammonia machine increasingly with greater divergence of the temperatures. At a temperature of about 60° Fahr. for the liquid (reaching the expansion valve) the one single loss of efficiency ξ in a carbonic-acid machine amounts to about one-third of the entire maximum efficiency, while the actual efficiency of the ammonia machine tested at Munich shows (according to the second last column of Table I.) the sum of *all* losses whatsoever not to exceed this amount. If the temperature of the liquid attains 88° Fahr., every useful effect derived from the evaporation of carbonic acid ceases, because the liquid heat imparted from the condenser to the refrigerator is then sufficiently great to neutralize the entire heat of evaporation.*

It has been attempted to reduce the loss of efficiency ξ by inserting a "feed-cylinder" between condenser and refrigerator for the purpose of performing the adiabatic expansive process. Hitherto such endeavors have not been attended by success. But in the event even of the existing obstacles being surmounted (notably those arising from variations in the ranges of temperature), it should be clearly understood that, by this expansion process, at best only a part of the theoretically available work

—that the values of G resulting by taking into account the precise values of $A(b_c p_c - bp)$ shall be re-arranged here in the following table :

	Sulphurous Acid.			Ammonia.			Carbonic Acid.		
$t_c =$	50° F.	68°	86°	50°	68°	86°	50°	68°	86°
$t =$ 32° F.	0.024	.049	.073	0.024	.046	.071	0.259	.461	.884
14°	.046	.070	.094	.040	.063	.088	.294	.489	.899
− 4°	.064	.090	.115	.055	.079	.105	.326	.516	.915

* The actual presence of these conditions at a temperature of 88° Fahr., *i.e.*, at the critical temperature for carbonic acid, can be proved by the following :

The total heat λ for saturated vapors is, for a higher temperature t_c, greater than for a lower temperature t. As $\lambda = q + r$ there will be $q_c - q > r - r_c$. If the higher temperature t_c be now raised to the critical temperature t_R, for which the latent heat is $= 0$, we find:

$$q^R - q > r.$$

Close to the critical point $q_R - q$ is very near to r; the further the temperatures t_R and t will be separated, the smaller the value r becomes as compared with $q_R - q$.

will be recovered, and that, for the condition of t_c approaching the critical temperature, the feed-cylinder will, at the close of expansion, contain only a very small quantity of liquid carbonic acid in consequence of by far the greater part having been vaporized. Hence the vapors aspirated by the compressor originate for the smaller part only in the refrigerator having been principally formed in the feed cylinder. The compressor capacity having to correspond to the volume of the vapors generated both in the feed-cylinder and refrigerator, it follows that its size, as well as that of the feed-cylinder, will demand a very considerable enlargement.

Another device for diminishing the loss of efficiency ε consists in allowing the liquid during its flow to expand primarily from the condenser pressure to an intermediate pressure, whereupon the vapors hereby developed are returned by an auxiliary compressor to the condenser. The remaining liquid is subsequently introduced into the refrigerator in the ordinary way.

It is, however, plain, firstly, that in this manner the harmful influence of the relatively great heat of liquid can be balanced only partly, and secondly, that these means will prove entirely useless when the initial temperature of the cooling water approaches the critical temperature.*

Besides the caloric loss in efficiency just dealt with, quite a series of other well-known losses occur in compression machines; they result partly from an interchange of heat with the surfaces of the cylinders, influence of the clearance spaces, leakages through pistons and valves, losses of pressure arising from

* The unfavorable consequences for the performance of the carbonic-acid machine near the critical point, as they result from the physical facts just referred to, have been frequently denied, and cases have been pointed out in which such machines actually work with higher temperatures of cooling water. The explanation of the apparent contradiction is, firstly, that often the final temperature of the cooling water (which exceeds the critical point) is kept in view, while its initial temperature is the determining feature for the present consideration; secondly, that admittedly it is possible to abstract a relatively small amount of heat also in the case of the initial temperature exceeding the critical temperature by maintaining a refrigerator pressure far below that corresponding to the temperature at which heat is to be abstracted from the body to be cooled. From what has been said above, no heat can then be eliminated by evaporation, but it is possible for the vapors of very low temperature, in passing through the refrigerator coils, to take up a certain (specific) heat. The refrigerative performance of the machine is then based on the same principle as that of a cold-air machine (with closed cycle).

internal resistance (especially by valve-throttling), and are caused partly by external resistances (friction).

FRICTION.

The amount of loss in efficiency due to friction is rightly considered as being dependent on the dimensions of the compressors as they are determined by the various fluids.

It is well known that this point forms one of the main causes for the relatively large motive power required by ether machines, for which the frictional work amounts to from 20 to 30% of the indicated work. For sulphurous-acid machines Schröter* has found the former to be 10 to 11%, and for Linde ammonia-machines 5 to 7%. The question arises: "Can any further economy be secured by the adoption of carbonic acid?"

The answer will be in the negative.†

LOSSES IN PRESSURE.

Valve-resistance.

The influence of the losses in pressure is, however, not insignificant, *i.e.*, the difference between the refrigerator pressure and the pressure in the compressor during the aspiration period, and that between the condenser pressure and the pressure in the compressor during the period of isothermal compression. If these respective pressure-lines are drawn upon the indicator diagrams, it is at once plain that the areas of loss are the larger, the smaller the mean pressure will be; and this may be figured approximately as follows:

Let the loss of pressure on the suction side amount to 1.80 lbs. per square inch, and that on the delivery side to 2.25 lbs.,‡ and

* *Untersuchungen an Kältemaschinen*, Munich, 1887, pp. 117–139; *Vergleichende Versuche an Kältemaschinen*, Munich, 1890, pp. 65–79.

† The dimensions of the ammonia compressors are already so small that, as a rule, their length of stroke is retained also for carbonic acid, because any diminution of the stroke would act unfavorably upon the clearances, and would subject the driving gear to comparatively large stresses. For the same stroke the strains transmitted by the piston upon the driving parts, and consequently also the friction in main bearings, crank-pin, and slides, will be somewhat larger (for reasons stated) than for ammonia. The piston ring friction might, on account of the smaller circumference of piston, be a trifle less for carbonic acid, but this is balanced by the increased friction of the piston rod due to its having to be packed against high pressure.

‡ These are values corresponding to measurements on well-constructed compressors working at moderate speed (*v.* the publications by Schröter, previously referred to).

let the period for isothermal compression amount to 40% of the stroke, then the sum of these losses in pressure will be 2.70 lbs. per square inch on the piston for the entire stroke. For a mean indicated pressure of 27 lbs. for sulphurous acid, 56 lbs. for ammonia, and 330 lbs. for carbonic acid, the losses by pressure result respectively as 14.8%, 5.0%, and 0.8%.

Sulphurous Acid.—This fluid offers in none of the directions just discussed any advantage as to efficiency in comparison with ammonia; on the contrary, the previous considerations demonstrate the actual efficiency of the sulphurous-acid machines to be far behind that of ammonia machines, and such has also been established by the exhaustive comparative tests made under Schröter's direction in the years 1886–1889 on several Pictet machines, which have been published in the reports repeatedly referred to in this paper.

Carbonic Acid.—As regards carbonic-acid machines, it must be regretted that actual results have hitherto not been published. Observations from private tests which have come to the author's knowledge entirely confirm what has been said before. The efficiency differs but slightly from that of ammonia machines as long as the range of temperature is very small; but with increasing temperature the efficiency decreases (as per Table IV.) so rapidly that, for instance, for a refrigerator temperature of 14° Fahr., and a cooling water temperature initially of about 60° Fahr., the consumption of power for a carbonic-acid machine (producing an equal quantity of cold) is at least 50% greater than for an ammonia machine.

Ammonia.—Considerations as to the physical properties of ammonia, and the results of reliable tests hitherto published, confirm that ammonia-compression machines show the highest efficiencies among the various refrigerating machines for all temperature ranges possessing practical importance. There may be other justifiable reasons rendering for certain special circumstances the use of cold-air machines, carbonic-acid machines, and absorption machines preferable, but then the attainment of the highest possible efficiency must be a second consideration.*

* It is not meant to be conveyed that *every* ammonia-compression machine is superior to any absorption, or carbonic-acid machine. The difference in the actual efficiency of different machines belonging to one and the same system is sufficiently great to enable a well-constructed absorption or carbonic-acid machine to be far superior to a badly built ammonia-compression machine. What is here said refers expressly to machines of equally good construction.

CONCERNING TEST-TRIALS ON REFRIGERATING MACHINES.

The further elucidation of questions dealing with the actual efficiency of refrigerating machinery is dependent on the exact performance of test-trials. For a comparison between the results thus obtained, it is not only of value to know them as being derived from quite correct measurements, but these last must be carried out on a *common basis*, so that the test programme will be one and the same for certain important points. For similar purposes (for instance, for evaporation tests on steam-boilers, for efficiency tests on steam-engines, for trials on pumping engines) the engineering profession has agreed to the adoption of standard testing rules. It would be of the highest importance for the field of refrigerating machines, if such a programme would meet with the consent of all concerned, in order that the same may be applied in all cases where it is intended to compare the trial results with those obtained elsewhere.

General Programme.—The author submits here his suggestions for a standard programme, and invites discussion on the main points to be considered. The following questions will have to be dealt with:

"What shall be measured?"

"How shall the measurement be made?"

"How are the results to be tabulated and utilized for purposes of comparison?"

A reply to the first two questions will be found on considering that the purpose of the test is to determine the ratio of consumption and production, so that there will have to be measured both the refrigerative effect and the heat (or mechanical work) consumed, also the cooling water. By *refrigerative effect* is understood the product of the number of heat units (Q) which are abstracted from the body to be cooled, and the quotient $\frac{T_c - T}{T}$; that is to say, the difference between the temperature T_c at which the heat is transmitted to the cooling water, and the temperature T at which the heat is to be taken from the body to be cooled, divided by this latter (absolute) temperature.

The determination of the *quantity of cold* will be possible with the proper exactness only when the machine is employed during the test to refrigerate a liquid, and if the cold be found from the

quantity of liquid circulated per unit of time, from its range of refrigeration, and from its specific heat. Sufficient exactness cannot be obtained by the refrigeration of a current of circulating air, nor from the manufacture of a certain quantity of ice, nor from a calculation of the fluid circulating within the machine (for instance, the quantity of ammonia circulated by the compressor). Thus the refrigeration of brine will generally form the basis for tests making any pretension to accuracy; at the same time, the degree of refrigeration should not be greater than necessary for allowing the range of temperature to be measured with the necessary exactness; for this a range of temperature of from 5° to 6° Fahr. will suffice.

The same reasoning will apply to the *condenser measurements* for cooling water and its temperatures; these will be possible with sufficient accuracy only with submerged condensers, seeing that for evaporative surface condensers atmospheric influences play a part which cannot be taken into account with sufficient certainty. The measurement of the *quantity of brine* circulated, and of the cooling water, is usually effected by water meters inserted into the conduits. If the necessary precautions are observed this method is admissible. For quite precise tests, however, the use of two accurately gauged tanks must be advised, which are alternately filled and emptied.

To measure the *temperatures of brine and cooling water* at the entrance and exit of refrigerator and condenser respectively, the employment of specially constructed and frequently standardized thermometers is indispensable; no less important is the precaution of using at each spot simultaneously two thermometers, and of changing the position of one such thermometer series from inlet to outlet (and *vice versa*) after the expiration of one-half of the test, in order that possible errors may be compensated.

It is hardly necessary to point out the importance of determining with thorough precautions the *specific heat of the brine* used in each instance for its corresponding temperature range, as small differences in the chemical composition and the concentration of the brine may cause considerable variations. In every instance the nature of the brine and its concentration should be entered in the report.

As regards the *measurement of consumption*, the programme will not have to lay down any special rules in cases where only the measurement of steam and cooling water is undertaken, as will

be mainly the case for trials of absorption machines. For compression machines matters lie less simply, because with them the steam consumption depends both on the quality of the steam-engine and on that of the refrigerating machine, while it is evidently desirable to know the consumption of the former separately from that of the latter. As a rule, steam engine and compressor are coupled directly together, thus rendering a direct measurement of the power absorbed by the refrigerating machine impossible, and it will have to suffice to ascertain the indicated work both of steam-engine and compressor. By further measuring the work for the engine running empty, and by comparing the differences in power between steam-engine and compressor resulting for wide variations of condenser pressures, the effective consumption of work L_e for the refrigerating machine can be found very closely. In general, it will suffice to use the indicated work found in the steam-cylinder, especially as from this observation the expenditure of heat can be directly determined. Ordinarily the use of the indicated work in the compressor cylinder, for purposes of comparison, should be avoided; firstly, because there are usually certain accessory apparatus to be driven (agitators, etc.), belonging to the refrigerating machine proper, and secondly, because the external friction would be excluded.

Heat Balance.—We possess an important aid for checking the correctness of the results found in each trial by forming the balance in each case for the heat received and rejected. Only such tests should be regarded as correct beyond doubt, which show a sufficient conformity in the heat balance. It is true that in certain instances it may not be easy to account fully for the transmission of heat between the several parts of the machine and its environment by radiation and convection, but generally (particularly for compression machines) it will be possible to obtain for the heat received and rejected a balance exhibiting small discrepancies only.

REPORT OF TEST.

Reports intended to be used for comparison with the figures found for other machines will therefore have to embrace at least the following observations:

Refrigerator:

Quantity of brine circulated per hour.....

Brine temperature at inlet to refrigerator.....

Brine temperature at outlet of refrigerator..... ..... t
Specific gravity of brine (at 64° Fahr.)..... .....
Specific heat of brine .....
Heat abstracted (cold produced)..... ..... Q_e
Absolute pressure in the refrigerator.....

Condenser :

Quantity of cooling water per hour.....
Temperature at inlet to condenser.....
Temperature at outlet of condenser..... t
Heat abstracted..... Q_1
Absolute pressure in the condenser .....
Temperature of gases entering the condenser.....

ABSORPTION MACHINE.

Still :

Steam consumed per hour.....
Absolute pressure of heating steam..... .....
Temperature of condensed steam at outlet... .....
Heat imparted to still..... Q'_e

Absorber :

Quantity of cooling water per hour .....
Temperature at inlet ....
Temperature at outlet .....
Heat removed..... Q_2

Pump for Ammonia Liquor :

Indicated work of steam-engine
Steam consumption for pump..
Thermal equivalent for work of pump..... $A\,Lp$

Total sum of losses by radiation and convection..... $\pm\ Q_3$

Heat Balance :

$Q_e + Q'_e = Q_1 + Q_2 \pm Q_3$.

COMPRESSION MACHINE.

Compressor :

Indicated work..... L_t
Temperature of gases at inlet..
Temperature of gases at exit...

Steam-engine :

Feed-water per hour.....
Temperature of feed-water....
Absolute steam pressure before steam-engine.....
Indicated work of steam-engine. L_e
Condensing water per hour ....
Temperature of d_a.....

Total sum of losses by radiation and convection..... $\pm\ Q_3$

Heat Balance :

$Q_e + AL_c = Q_1 \pm Q_3$.

For the calculation of efficiency and for the comparison of various test results, the actual efficiencies must be compared with the theoretical maximum of efficiency $\left(\frac{Q}{AL}\right)$ max. $= \frac{T}{T_c - T}$ corresponding to the temperature range.

Temperature Range.—As temperatures (T and T_c) at which the heat is abstracted in the refrigerator and imparted to the condenser, it is correct to select the temperature of the brine leav-

ing the refrigerator and that of the cooling water * leaving the condenser, because it is in principle impossible to keep the refrigerator pressure higher than would correspond to the lowest brine temperature, or to reduce the condenser pressure below that corresponding to the outlet temperature of the cooling water.†

Some reports on test trials contain as temperature limits the temperatures corresponding to the actual gauge-pressures observed in the condenser and refrigerator. But such a method does not take into account the real temperature range, as it is prescribed by the requirements of each case; temperature ranges are rather introduced which are created by the machine itself. It is universally recognized that (under otherwise equal conditions) that machine will possess the highest efficiency for which the refrigerator pressure corresponds as nearly as possible to the temperature down to which the body to be cooled is refrigerated, and for which, in like manner, the condenser pressure corresponds most closely to the outlet temperature of the cooling water. If, for judging the machines, the actual pressures were chosen as a starting-point, just those machines would appear to be frequently credited with the higher efficiency, the performances of which—as a consequence of the imperfections present—are less satisfactory.‡

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* The (theoretically) attainable lowest limit of the outlet temperature (for submerged condensers) will be the temperature corresponding to the transmission of heat to the cooling water equal to the cold produced (Q), plus the heat-equivalent to the mechanical work $AL = Q\frac{T'_c - T}{T}$. In compression machines the sum $Q + AL$ is influenced so slightly by the deviations of the actual work from the theoretical work, that we may unhesitatingly select as starting-point the actual outlet temperature. In absorption machines, however, this is permissible only when the cooling water is passed first through the condenser, and afterward through the other apparatus.

† While it is requisite to look upon the outlet temperature of the cooling water (on account of the pressures) as the constant rejection temperature for the principal part of the heat to be abstracted (*i.e.*, the latent heat), it is true that for a small portion of the heat to be removed (*i.e.*, the part serving to reduce the liquid heat), the initial temperature of the cooling water can be considered as the determining feature.

‡ The publication by Denton and Jacobus, already referred to (*Trans. Amer. Soc. Mech. Engrs.*, Vol. XIII.), contains an instance of erroneous conclusions drawn from this latter method of selecting the temperature range. For the Pictet machine and the Linde ammonia machine tested at Munich under Schröter's direction, the temperatures resulting from the refrigerator and condenser press-

Even the proper comparison between the performances of one and the same machine working under the same external but different internal conditions, is rendered misleading by the method here referred to. Assuming an ammonia-compression machine to work uniformly at a certain brine temperature and a certain outlet temperature of cooling water, but receiving in one case wet and in the other dry vapors, in the latter case the refrigerator pressure will be less and the condenser pressure higher than in the former case. It is evident that in both instances the required duty consists in lifting the heat to be abstracted from the same lower to the same higher temperature level, and that we can estimate the influence created by the different working processes correctly only by taking into account the levels prescribed from the outset, and not the fluctuating levels dependent on the fluctuations to which the ammonia has been subjected. Such a method may be serviceable for ascertaining the efficiency of single parts of the refrigerating machine; for instance, of the compressor, but not for the determination of the efficiency of the entire machine. Certainly it should not be neglected to record the pressures in refrigerator and condenser; but, valuable as these observations may be for the investigation of the several single performances carried out in the machine, it is necessary always, for comparing the true refrigerative effects of different machines, to start

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ures are employed by the reviewers for the determination of the efficiencies, although it had been expressly prescribed from the outset and carried out during the tests, that both machines should refrigerate the same brine through the same range of degrees down to the same temperature, and that the cooling water should enter and leave the machines at the same respective temperatures. Under these conditions the Pictet machine received per 1,000 B. T. U. in the average 63 lbs., and the Linde machine in the average 59 lbs. (Denton and Jacobus represent the Pictet machine as having received less cooling water, evidently mistaking the absolute quantities for the relative amounts.) Hence Denton and Jacobus are led to find from these calculations nearly the same efficiency for both machines, while the actual surplus in efficiency of the ammonia machine amounted from 20% to 30% beyond that of the Pictet machine, according to the plain statement of Schröter, accepted by Pictet.

If, in the Pictet condenser, the difference between the temperature corresponding to the condenser pressure and the outlet temperature of the cooling water had been still greater, that is to say, if the process performed by the Pictet machine had shown still greater imperfections, the efficiency would probably, according to Denton and Jacobus's method, have resulted as being higher, or at least equal to that actually found. Hence the necessity for an accurate and definite conception of "refrigerative effect" and the corresponding "ranges of temperature."

from temperatures which are independent of the class and construction of the machine and which are specified by the outside conditions of each case, just as for judging a water-works plant we start invariably from the really required height of lift, and not from any pressures which may be present at some particular point of the system.

We have therefore to insert into the formula for the theoretical maximum efficiency:

$$T_c = 460 + t_c^\circ \text{ Fahr., and } T = 460 + t^\circ \text{ Fahr.}$$

The ratio η between the actual and the theoretical maximum will thus follow:

$$\eta = \frac{Q_e}{AL_e} : \left(\frac{Q}{AL}\right) \text{max.} = \frac{Q_e}{AL_e} \times \frac{t_c - t}{460 + t}.$$

But for purposes of comparison between compression and absorption machines there must be introduced the actually spent quantity of heat $Q'_e = \frac{1}{\mu} AL_e$, and we obtain for the comparison of two different machines of each kind the ratio:

$$\eta_c = \mu\eta = \frac{Q_e}{Q'_e} \times \frac{t_c - t}{460 + t}.$$

APPENDIX.

The test No. 3 of the five tests, the results of which are contained in the Tables I., I.*a*, and III., has been repeated, and the results are now the following, being in still a more satisfactory accord with the other tests.

TABLE I.

ACTUAL PERFORMANCE OF AMMONIA COMPRESSION MACHINES.

No. of Test	1	2	3	4	5
Temperature of refrigerated brine.. Inlet, deg. Fahr.			13.952		
Temperature of refrigerated brine.. Outlet, deg. Fahr. (t)			8.771		
Specific heat of brine per unit of volume			0.8427		
Quantity of brine circulated per hour, pounds			633.89		
Cold produced, B. T. U. per hour (Q)			172,776		
Temperature of cooling water in condenser.. Inlet, deg. Fahr.			48.931		
Temperature of cooling water in condenser.. Outlet, deg. Fahr. (t_c)			67.282		
Quantity of cooling water per hour, pounds			187,506		
Heat eliminated by condenser, B.T.U., per hr.			214,796		
I. H. P. in compression cylinder (L_c)			13.53		
I. H. P. in steam engine (L_s)			15.28		
Consumption of steam per hour, pounds			305.87		
Cold produced per hour, B. T. U. — Per I. H. P. in comp. cylinder			12,770		
Cold produced per hour, B. T. U. — Per I. H. P. in steam cylinder			11,307		
Cold produced per hour, B. T. U. — Per pound of steam			564.9		
$\eta = \frac{Q}{AL_c} \times \frac{t_c - t}{460 + t}$			0.606		
$\frac{Q}{Q'}$ = Cold produced ÷ heat expended			0.509		

TABLE I.*a*.

ACTUAL PERFORMANCE OF AMMONIA COMPRESSION MACHINES, ASSUMING A COMPOUND STEAM-ENGINE AS MOTOR.

No. of Test	1	2	3	4	5
$\frac{Q}{Q'}$ = Cold produced ÷ heat expended	.....	.....	0.713	.....	.....

TABLE III.

No. of Test	1	2	3	4	5
Temperature of cooling water leaving condenser, deg. Fahr. (t_c)	.....	.....	68	.....	.....
Final temperature of refrigerated brine, deg. Fahr. (t)	.....	.....	8	.....	.....
Actual efficiency of Compression machine ÷ theoretical efficiency of Absorption machine. According to Table I.	.....	.....	0.977	.....	.....
Actual efficiency of Compression machine ÷ theoretical efficiency of Absorption machine. According to Table I*a*	.....	.....	1.368	.....	.....

The report of all five tests is now published in No. 25 of *Bayerisches Industrie und Gewerbeblatt*, Munich, 1893.

DISCUSSION.

Prof. D. S. Jacobus.—On page 1431 of the paper there is a foot-note which calls for a reply to its two criticisms. In the first case, Professor Linde claims that if we wish to obtain the theoretical efficiency of a machine we should take the highest temperature of the condensing water and the lowest temperature of the brine. This is correct in one way and incorrect in another. If we desire to obtain the efficiency of the machine, including the efficiency of transmission, then we might employ the particular temperatures recommended by Professor Linde, and afterward obtain the efficiency by using the vapor temperatures, and show how much loss there is by transmission. All through our work, however, it is specified that vapor temperatures shall be used. We calculated the theoretical efficiency by using the vapor temperatures and comparing with the actual efficiencies shown by tests. It is stated that we cannot exceed the limit of the temperature of the condenser, and we cannot fall below the limit of the lower brine temperature. This is correct, but the machine is actually working up to the temperature of the vapor in the condenser, which is constant for a given pressure inside of the condenser tubes, and down to the temperature of the vapor in the brine coils. The moment we assume any other than

the vapor temperatures we have to make assumptions, and take either the highest, the lowest, or the average temperatures of the condensing water and brine. By far the most logical way is to take the actual temperatures which exist in the vapor, and then, if we wish to do so, find the loss due to transmission separately.

Now, in regard to the amounts of cooling water used in the tests of the Linde and Pictet machines. Before starting to make these tests it was agreed that the range of condensing water should be made the same for each machine. This was hardly fair, although it appears all right at the first glance. Let us take the actual case as it was, and then I will explain why it was not correct to take the range the same in each. The tests were made on two machines which had about the same indicated horse-power. The quantities which show the economy of the machines are the pounds of ice made per indicated horse-power per hour, and the pounds of ice made per pound of steam furnished to the engine. Why was not the Pictet machine, therefore, entitled to as much condensing water per indicated horse-power or per pound of steam as the Linde machine? The Pictet machine was furnished with 15 to 28% less condensing water per indicated horse-power than the Linde, and from 30 to 45% less per pound of steam used. Again, it might be contended that the same amount of condensing water should be furnished per indicated horse-power at the ammonia cylinder. The only other unit we can employ is that given by Professor Linde, which is based on the output of the machine. If we take the output, the Pictet machine had more condensing water per pound of ice than the Linde; we should not, however, endeavor to make this quantity the same in each machine, but we should furnish each machine with the same amount of material to do the work and let the output come what it will. It is stated by Professor Linde that the theoretical performance of an absorption machine is less than the actual performances which are attained by compression machines; this is correct for some conditions of refrigeration, but not for others.

Now, in this little book, which gives the theories of Ledoux, we have practically the same cases calculated out as Professor Linde has given, and the most economical rate of steam consumption that we have assumed for the engine of the compression machine corresponds very nearly with the figure of 14 pounds per hour per horse-power employed by Professor Linde. In our calculations we employed 1.6 pounds of coal per hour per horse-power as the most

economical figure, and in addition we also assumed 3 pounds, which corresponds to the practice of to-day for compression refrigerating machines. Our results for the particular temperatures of the vapor assumed by Professor Linde agree with his; that is, the theoretical performance of the absorption machine is below that of a compression machine, assuming that the steam used by the engine of the compression machine is 14 pounds per hour per horse-power. But there are some cases where we can employ an absorption machine where it will be ahead of the compression machine, even assuming the low rate of 14 pounds of steam per hour per horse-power for the compression machine. This is from the theoretical standpoint. But all tests that have been made indicate that the theoretical formulæ predict correct results. Theory shows that the absorption machine gives the best results in comparison with those of the compression type as we decrease the temperature of the brine and increase the temperature of the condensing water. The efficiency of each machine falls, but when we compare the absorption with the compression machine we find a better economy with the absorption machine at low temperatures. So that in this table, where we have a temperature of vapor in the condenser of 86°, and a pressure in the brine coils of about that of the atmosphere, the absorption and the compression machines give about the same economy, provided the steam per hour per horse-power in the compression machine is 14 pounds. If we go still further we find that when the vapor temperature at the condenser is 100°, and there is a low pressure in the refrigerating coils, the absorption machine is far ahead. Of course, there needs to be a practical test made to verify this, but nevertheless the theory has been partly confirmed by tests made on absorption machines.

There is a statement made in regard to the relative efficiency of the ammonia and sulphur dioxide machines. The only tests quoted, as I understand it, are those tests by Professor Schröter. These were made in the most skilful and scientific manner, but more condensing water should have been used in the case of the Pictet machine. All that I have said in reference to the ammonia and sulphur dioxide machines does not deny the fact that there may be a difference in the transmission losses in favor of the ammonia machine, but this point is not raised by Professor Linde.

Mr. A. Sorge.—I agree that, by means of Professor Jacobus's method, we get the actual theoretical efficiency of the machine; but it is the purpose of all tests like those made in Munich, and

criticised by Professors Denton and Jacobus, to show how far a certain machine succeeds in performing a required work. If you want to compare two types of refrigerating machines, you can only do it by giving to each type or to each machine the same work to perform, and this work must be specified by a certain number of B. T. U. to be removed from the brine to the cooling water between certain temperatures; these temperatures are to be outside temperatures, just because the losses by transmission should be included in the result of the tests. For the transmission is one of the points on which the superiority or inferiority of a certain machine may depend. Concerning this point Professor Linde says in his paper the following:

"Some report on test trials (page 1431) . . . and not the fluctuating levels dependent on the fluctuations to which the ammonia has been subjected (page 1432)."

If you compare different types you usually take machines developing about the same amount of horse-power. Both machines being of the same quality, they will both extract the same number of B. T. U. from the brine and deliver them to the cooling water; that is to say, if the initial temperatures and the circulated quantities of the brine and cooling water are the same, the final temperatures of both will be the same. Now suppose one of the tested machines inferior to the others, then, of course, these final temperatures will not be the same, but come nearer together than in the better machines. But everybody knows that the smaller the temperature ranges are, the nearer the practical work comes to the theoretical. So, taking the same amount of cooling water in the condenser, a refrigerating machine working in reality worse than another one, may nevertheless show a higher efficiency when calculated in Professor Jacobus's way. I think this fact proves clearly that, for the purpose of comparing different types of machines, not the quantity of cooling water should be taken the same, but only the initial and the final temperatures.

Professor Jacobus.—It occurs to me to add that perhaps there may be a simple misunderstanding in the whole matter. When we calculated the actual efficiency of the machine, of course we used the actual temperature of the brine and of the condensing water, but when we calculate the theoretical efficiency we take the actual temperatures at which the heat is transferred. The theoretical efficiency of all the machines was calculated between the actual temperature through which the vapor was worked, which is by far the

most logical way to calculate efficiencies. Very likely a great deal of this difference in opinion comes from not appreciating the fact that the actual temperatures of the brine are used in getting the practical results, and all the difference between these practical results and the theory is shown up in the table as being a difference in percentage between the actual and the theoretical figures.

Mr. Sorge.—What should be exacted instead of the equality of the temperature range? We must have something by which we may specify the same work to be performed by both kinds of machines.

Professor Jacobus.—The same amount of material should be furnished to each machine. If you furnish one machine with twenty horse-power, then furnish the other machine with the same horse-power. If you give one machine a certain amount of condensing water, then give the other machine the same amount.

Mr. Sorge.—As to the cooling water, I refer to what I said before. The users of refrigerating machines have no desire to know what cooling effect they may get by means of a given amount of material; they only ask which machine will do the work required in the cheapest way, *i.e.*, with the least amount of material. But even admitted that it would be of value to make tests in the way just suggested by Professor Jacobus, I don't see how to give actually the same amount of horse-power to two different machines without involving complicated installations not feasible for practical use.

Professor Jacobus.—There would be some difficulty in accomplishing this; but in the particular case of the machines tested by Professor Schröter, where the discrepancy in the amount of condensing water was so large, it seems too bad that two or three tests were not made with the same amount of condensing water. We simply made the remark, in the paper criticised by Professor Linde, that if the amount of condensing water had been greater in the tests of the Pictet machine, the pressure at the condenser would have been lower, and probably the machine would have shown up better. If it comes to suggesting the proper way of making a test, I should say that each machine should be furnished with the same amount of condensing water per horse-power.

Mr. Sorge.—Mr. Chairman, I ask to offer the following resolution to the meeting:

Resolved, That it be recommended to the Council of the American Society of Mechanical Engineers to appoint a Committee to decide upon Standard Rules for

testing Refrigerating Machines, and who will, in doing this, correspond and act in concert with the Polytechnical Society in Munich, and with the Munich Committee for testing refrigerating machines.*

Prof. C. Linde.†—Professor Jacobus substantiates against the contents of the paper two objections, which he bases upon mistaken acceptations, requiring correction.

CONDENSING WATER.

In the Munich trials he says: "The Pictet machine was not entitled to the same amount of condensing water as the ammonia machine." This acceptation, with the conclusion drawn from it, is erroneous. For:

(1) The quantity of condensing water for the steam-engine was not limited in any way whatsoever.

(2) If Pictet gave his steam-engine less condensing water, naturally only the steam consumption would thereby be affected, and not the indicated horse-power. But as the comparisons of the figures contained in this paper only have reference to the amount of horse-power required by each machine, and not to the amount of steam, so the difference objected to by Jacobus has not the slightest influence on the disputed question.‡

(3) The quantity of cooling water for the condensers of the refrigerating machines was determined by fixing the range of temperature. From this it follows, quite as a matter of course, that for the same quantity of heat transmitted by each machine *the same quantity of water* must of a necessity have been supplied. Manifestly, this was the only correct method by which the machines could be allowed to work under the same conditions, and, therefore, it will scarcely require any further justification.

RANGES OF TEMPERATURE FOR COMPARING THE DETERMINATIONS OF THE EFFICIENCIES OF DIFFERENT MACHINES.

Professor Jacobus says: "If we desire to obtain the efficiency of the machine, including the efficiency of transmission, then we might

* This motion was duly put and carried.

† Author's Closure, under the Rules.

‡ The quantity of injection water was determined in the majority of the trials by the required quantity of cooling water for the condensing of the ammonia, having an outlet temperature of 68° F. (about). This quantity of injection water was, as a rule, too large for the steam-engine of the ammonia machine, and entirely sufficed in the case of the Pictet machine, being, on the average, not less than thirty-eight times as great as the steam consumption.

employ the particular temperatures recommended by Professor Linde, and afterwards obtain the efficiency by using the vapor temperatures, and show how much loss there is by transmission."

. . . "By far the most logical way is to take the actual temperatures which exist in the vapor, and then, if we wish to do so, find the loss due to transmission separately."

Here the fundamental error manifests itself on which that method of determining the efficiency is based, which I disputed in my paper. It exists in the acceptance that the difference between the temperature of the vapor and that of the surrounding liquid (cooling water in condenser, brine in refrigerator) is exclusively a necessary consequence of the resistance to the transmission of heat common in all machines.

Were this acceptance correct, then two machines of different systems, with the same surface areas and the same amount of cold production, must always show the same differences of temperature, and these differences would only be dependent on the size of those cooling surfaces.

Were this the case, the method defended by Professor Jacobus for the comparison of different machines would not be objected to.

In reality, however, these differences of temperature are also dependent on the construction and working of the whole machine; for instance, on the manner in which the refrigerating fluid is introduced into each coil, and in which the sectional areas are chosen in proportion to the surface areas; on the arrangement of the collecting pieces and the pipe lines; on the degree of superheating of the vapor leaving the compressor, and so on; therefore, from a great number of circumstances which the maker of the machine intentionally, or unintentionally, produces, his duty consists, to not a small degree, in achieving with the smallest surface areas the smallest differences of temperature. It succeeds, as a matter of fact, in very varying degrees.

For an example, I just referred to the results of the Munich trials, in which the Pictet machine, notwithstanding smaller quantities of heat transmitted with the same surface area and the same quantity of water, showed far larger differences of temperature than the ammonia machine. And in the case of this same ammonia machine, the latest trials (given in with this paper) have again, in consequence of improvements in construction, shown a substantially smaller difference of temperature than the earlier ones.

It cannot be too strongly emphasized. The difference between

the vapors on the one side, and the cooling water and brine on the other, are a dependent product of the quality of the machine.

An essential part of the imperfections and losses of the machine is not accounted for when the vapor temperatures are taken as a measure of the efficiency. An exact comparison of the efficiencies of different machines can only be based on the temperatures of the bodies from which heat is extracted in the refrigerator, and to which heat is delivered in the condenser.

DLV.

MEMORIAL NOTICES OF MEMBERS DECEASED DURING THE YEAR.

JAMES MORGAN.

James Morgan was born at Carmarthenshire, South Wales, April 27, 1843. He received the training of a blacksmith at Oakfield Iron Works, Monmouthshire. In May, 1864, he came to the United States and settled in Pittsburg, filling leading positions in the United States Arsenal and railway shops. In 1866 he was appointed in charge of the smith shops of the Jones & Laughlins Iron and Steel Works, assuming charge later of their boiler-shop and blast-furnace building. He became structural engineer for the company until his resignation in 1890, caused by ill health. He had designed a number of special machines for rivet-making and boiler-shop work and a suspended feed-table for rolling-mills. He became a member of the Society at its Pittsburg meeting in May, 1884, and died June 4, 1892, from nervous prostration.

WILLIAM HENRY PATTON.

After receiving the degree of Civil and Mechanical Engineer, Mr. Patton devoted himself to mining and quartz milling from 1852 to 1886. From 1866 to 1874 he was constructing engineer for a number of silver and gold mining companies in Nevada and California, among them the Old Colony, Keystone, the Plumes-Eureka, etc. He was also assistant superintendent of construction of the United States Mint at San Francisco, and from 1874 to 1877 was constructing engineer for the syndicate Mackay, Fair, Flood, and O'Brien, in Virginia City. From 1877 to 1882 he was their mining engineer, and at the time of his death was mining engineer with the Broken Hill Mines, in New South Wales. He became a member of the Society at the New York meeting in 1882, and died in 1892.

WILLIAM J. ROOT.

William J. Root was born in New Haven, October 28, 1844, and was one of the early members of this Society. His application was dated October 29, 1880, and signed by Messrs. Henry R. Worthington and D. S. Hines, since deceased. At that time he had been for eighteen years, since March, 1863, connected with the hydraulic works, in charge of erection and tests, and of the drawing-room. In 1890 he connected himself with the Blymyer Ice Machine Co. of Cincinnati, with whom he remained until the spring of 1892, when he removed to New Haven, Conn. He died December 3, 1892.

JOHN FRASER WEBSTER.

John Fraser Webster was born March 20, 1848, at London, England. Served apprenticeship with Thomas Morthey & Co., Hamilton, Canada. In 1865 was employed by the Dundas Screw Co. as tool-maker, afterward working for the Buffalo Steam Engine Works. In 1870 was superintendent of the Lockman Sewing Machine Co., Hamilton, and afterward superintendent of Canada Sewing Machine Co., same place. In 1878 he came to Springfield, O., and took contracts with the St. John Sewing Machine Co., and two years later was employed in the Champion Bar & Knife Co., first in charge of a department and later as superintendent. He afterward became one of the firm of Webster & Perks Tool Co., which position he filled to the time of his death, which occurred on January 17, 1893, from disease of the kidney. During his residence in Springfield he became a prominent citizen and was universally respected and esteemed. He became a member of the Society in 1884 at the Pittsburg meeting.

ARTHUR TANNATT WOODS.

Arthur Tannatt Woods was born January 9, 1859, at Minneapolis, Minn. He graduated from the United States Naval Academy as cadet engineer, June 10, 1880. From that date to March 9, 1883, he was on duty in the engineering department of United States steamers *Despatch*, *Galena*, *Quinnebaug*, *Lancaster*, and *Nipsic*, most of his cruising being in the Mediterranean. On his return to the United States, in the spring of 1883, he was

promoted to the grade of assistant engineer, and was at once placed on duty at the Navy Department, in connection with the preparation of machinery designs for the new cruisers. In the summer of 1883 he was, at the urgent request of the trustees of that institution, ordered by the Navy Department to serve as professor of mechanical engineering at the University of Illinois, Champaign, Ill. At the end of four years' service in that capacity he resigned his commission as an officer of the navy and accepted a regular professorship at that university. Four years later he accepted the professorship of dynamic engineering at Washington University, St. Louis, Mo. During these years he published, jointly with a friend, a text-book on *Elementary Mechanism;* he also published a treatise on *Compound Locomotives,* on which subject he had become a recognized authority; and he became a regular contributor to engineering periodicals, especially on railroad matters. In August, 1892, he resigned his professorship and became associate editor of the *Railroad Gazette,* which position he occupied at the time of his death. He died in Chicago, February 7, 1893, of typhoid fever. He was a member of a number of dignified and important societies, had received the degree of M.M.E. from Cornell University, and had recently been appointed to a lectureship in the University of Chicago. He became a member of this Society in June, 1883.

JOHN FERGUSON HASKINS.

John Ferguson Haskins was born October 2, 1833, in Buffalo, N. Y. He served an apprenticeship at Buffalo with the Sheppard Iron Works, the Buffalo Steam Engine Company, and on the lakes from 1847 to 1852. He went to England with the first American mowing machine, which he introduced successfully abroad and took almost all of the many agricultural prizes which were then offered for such machines. In 1858 he became connected with Captain John Ericsson as draughtsman, and, later, was the manufacturer of the Ericsson caloric engine. About the beginning of the war he became identified with the Morgan Iron Works, and was closely connected with work on the first *Monitor,* much of the turret work and that relating to the big guns being in his hands.

In 1863, as shore agent for the Shanghai Navigation Company, Mr Haskins went to China on the steamship *Fookein,* which was chased half way to its destination by the cruiser *Alabama,* com-

pelling the destruction of everything combustible on board. Returning from China, he furnished the government of that country most of the necessary machinery for the first Chinese arsenal, and then entered upon the manufacture of horse-shoe nails at Forge Village, Mass. Subsequently, at Fitchburg, his connection began with the Burleigh Rock Drill Company; he developed one of the first air compressors which made rock drilling feasible, and was intimately connected with the work at the Hoosac Tunnel, at Hell Gate, and at the caissons for the East River Bridge up to 1871. He was also the manufacturer of the Haskins steam-engine at Fitchburg, and it was during this connection that the development of the steam and air Siren whistle was undertaken, which is so much used both on vessels and as fog signals. Upon the discontinuance of the Haskins Steam Engine Company he connected himself with the Stowe Flexible Shaft Company. He went to Europe in 1878 in charge of the European business of the Globe Horse Nail Company, and remained in London for ten years, making a specialty of American machinery. After a service as general sales agent for the Stearns Manufacturing Company, he became senior partner of the John F. Haskins Company, in Chicago.

He connected himself with the Society at the New York meeting of 1891, and his death, on February 25, 1893, was due to congestive asthma and heart failure.

MOSES G. FARMER.

Moses Gerrish Farmer, member of this Society, was suddenly removed by death at Chicago while attending the World's Columbian Exposition, where he had interesting collections, and where he had gone to study the great encyclopedia of all the arts which were there presented. Professor Farmer had long been an invalid, and his death caused no surprise among his friends.

Moses G. Farmer was born at Boscawen, N. H., February 4, 1820. He was educated at Phillips Academy, Andover, and at Dartmouth College, taking his A.M. in 1842. He taught school at Portsmouth, N. H., and at Eliot, Me., until 1846, when he commenced the formal application of his already exceptional knowledge of electricity and its applications, and was perhaps the first member of the profession styling himself "electrical engineer." He built an electric road in 1847 as an experiment

and on a small scale, operating it with an engine driven by forty-eight one-pint Grove cells. This railway was operated in Dover, N. H., Great Falls, South Berwick, and Portsmouth, N. H. From that time to the day of his death his mind was prolific of ingenious and often useful and valuable devices, mainly in the domain of applied electricity. He built the first fire-alarm telegraph and set it in successful operation in Boston in 1851–52. He invented an equal-impulse electric clock still earlier, made chronographs for Admiral Wilkes and the United States Exploring Expedition in 1853, with seven inches record per second, and for the Dudley Observatory, on the order of Dr. B. A. Gould, in 1856, and still others later. He devised, as early as 1853–55, "synchronous telegraphs," sending four messages at once on a single wire. Substantially the same device is described in the *Scientific American* of August 19, 1882, as reinvented abroad. The duplex telegraph, working by reversal of current, separately patented in 1858, constitutes one-half of the quadruplex.

House-lighting by electricity was first practised by Professor Farmer in 1859, his own house being lighted in July of that year by a battery of Grove cells, giving a current of sixty to eighty volts' tension and of three to four webers volume, traversing incandescent lamps. Dynamo-electric machines were invented by him and gradually perfected (1861-65), taking the form subsequently generally known as that of Wilde, Siemens & Wheatstone, but independently and earlier invented also by Hjorth. The year 1886 was signalized by the production of an extraordinarily large, powerful, and economical thermo electric battery of 3,744 pairs, connected up in series of 12, forming a 312 multiple-arc battery. It weighed 1,500 lbs. and over, and had an electromotive force of $\frac{7}{2}\frac{2}{4}\frac{0}{0}$ volts, while depositing $11\frac{3}{4}$ lbs. of copper in 24 hours, with a consumption of but 109 lbs. of fuel; *i.e.*, at present prices of best copper and coal, about one dollar's worth of copper with five cents' worth of coal. In connection with his telegraphic work he devised the "compound" wire, consisting of a core of steel surrounded by a shell of copper, thus uniting strength with conductivity and producing a wire supposed to be peculiarly well adapted to use where heavy snows were liable to break down the common iron telegraph line.

Professor Farmer was for some years connected with the United States Torpedo Station at Newport, R. I., and its first dynamo was supplied by him in the same form which had served

so good a purpose in his earlier work in electric lighting. This was in 1871–72, and he remained at this station in the employ of the United States Government and the Navy Department for about ten years, when partial paralysis compelled him to surrender his work. He spent some months at Dansville, N. Y., partially regained his working powers, and then, after a time, removed from Newport to Eliot, Me., where he held residence to the date of his decease.

In personal character Professor Farmer was as admirable as, professionally, he was talented. He was of a bright and cheerful disposition, kindly and considerate, forming strong friendships and holding his friends with indestructible bonds. His strong common sense, tempered in his harsher judgments by enthusiasms and hopefulness, led him to form correct estimates of proposed schemes, of which innumerable inventors were continually writing him, and of the probable outlook for his own plans. He never possessed, however, that business instinct so rarely characterizing inventors or students, and never acquired any large sums of money from the sale or use of his inventions.

CALVERT B. COTTRELL.

Mr. Cottrell began his mechanical career by an old-style apprenticeship in 1842, near his home in Rhode Island. In 1855 he formed the firm of Cottrell & Babcock, with Mr. George H. Babcock, but during the later period the firm was C. B. Cottrell & Sons, engaged in machinery for textile and wood-working industries, and more especially of printing presses, for which he was best known. He became a member of the Society in 1886 at the New York meeting, and died June 13, 1893.

JAMES G. R. GEMMELL.

James G. R. Gemmell was born July 20, 1852, in Fort Glasgow, Scotland. From 1864 to 1870 he served apprenticeship at Hull, England, with the Earle Shipbuilding and Engineering Company. After two years in their drawing office he went to sea. For the next four years he was draughtsman and superintendent engineer with James Moss & Co., Liverpool, and in 1876 became manager and consulting and superintending engineer with the firm of William Esplen & Son, where he remained until

1887, when he was appointed manager of the Canada Iron Works, Engineering & Shipbuilding Company, Birkenhead, where he remained until February, 1889, when he came to this country to become general superintendent of the Atlas Steamship Company of New York, in full charge of maintenance and repairs of hulls and machinery. He connected himself with this Society at the New York meeting in 1891; and his death, on June 16, 1893, was due to heart trouble.

ROBERT WHITEHILL.

Mr. Whitehill was born in Glasgow, Scotland, June 1, 1845, and came to this country with his parents in 1847, and resided at Wappingers Falls until 1857, when the family removed to Newburg. He graduated from the academy, and after a period as bookkeeper and cashier in New York City he entered the foundry of Stanton, Mallory & Co. to learn the trade of a machinist. He remained there until the suspension of the firm, and during that period, with his father's assistance, he invented a machine for sizing and dressing cotton yarn, which he put into operation at the Newburg steam mills, of which his father was superintendent. Subsequently he engaged as a journeyman with the Novelty Iron Works of New York, where he acquired valuable experience in constructing and erecting the machinery of steamships. A year later he entered the United States Navy as third assistant engineer. In 1865 he returned to Newburg and rented a portion of the steam-engine works of Corwin, Stanton & Co., and for five years thereafter was engaged, with his father as a partner, in the manufacture of his patented machinery. The changes which then occurred were the opportunity for the laying of the foundations of the Pictet Ice Machine Company, with which he has since been identified, and which brought him prominently forward as an engineer and machine builder. He was also interested in a manufactory of lawn-mowers.

For several years he was president of the Board of Trade of Newburg. In the years 1871 and 1872 he represented the Second Ward in the Common Council, and was president of the Board in the latter year.

He became a member of the Society at the Chicago meeting, in May, 1886, and died, after a lingering illness, July 17, 1893.

JAMES H. FITTS.

James H. Fitts was born on January 27, 1861, in Virginia. He graduated as cadet engineer at United States Naval Academy, June, 1882. Served in the United States Navy as cadet engineer and assistant engineer for one year, from July 1, 1884, to July 30, 1885. In August, 1886, he was chosen professor of Mechanics and Physics in the Virginia Agricultural and Mechanical College, making a specialty of applied mechanics and mechanical drawing.

During the last months of his life he had been actively concerned in perfecting the details of a surface condenser, in which the heat was to be abstracted from the cooling coals by evaporation. This had been made the subject of a paper to be presented at the Engineering Congress in Chicago in 1893, and had already received favorable comment from numbers of people interested in such matters.

While on his way to the convention he lost his life in an accident upon the railway, under very distressing circumstances, on the evening of July 24, 1893.

He became a member of this Society at the Providence meeting, June, 1891.

EDWARD STEWART MOFFATT.

Edward Stewart Moffatt was graduated from Princeton, N. J., and then entered the School of Mines at Columbia College, New York, graduating in 1868. From 1868 to 1870, adjunct professor Mining and Metallurgy, Lafayette College; 1870–72, engaged in civil engineering and metallurgical work in New Jersey; 1872–76, manager of Port Oram Iron Works, Morris County, N. J.; 1876–78, superintendent of construction Sycamore Iron Works; 1878–82, manager Musconetcong Iron Works, New Jersey, and in 1882, general manager of Lackawanna Iron and Coal Company at Scranton, Pa. At the date of his death was general manager of the Lackawanna Iron and Steel Company, formed by the consolidation of the old iron and coal company and the Scranton Steel Company.

He lost his life by his own hand in London, August 5, 1893.

He became a member of this Society at the New York meeting in 1883.

ERNEST VICTOR CLEMENS.

Ernest Victor Clemens was born April 3, 1855, at Waterbury, Conn. He was taken as a boy apprentice in the pattern shop of the Farrell Foundry and Machine Company, at Ansonia, Conn., where his father was superintendent, and passed successfully through the foundry and machine shop to the drawing room. His first important work was the installation of a sugar plant, to which he added machinery for mining and metallurgy and for rolling mill; also machinery for paper, grain, and metals. He became foreman of the pattern shop, and, later, head draughtsman, secretary and treasurer of the foundry and machine company, and superintendent of the National Machinery Company at Tiffin, Ohio, coming back to be assistant superintendent of the Farrell Company, and, since 1888, superintendent of the De La Vergne Refrigerating Company. He was also consulting engineer for the Central Forge Works, and treasurer of the White Cloud Copper Mining Company.

His last work, in his present relations, had been the installation of a new shop of large tools, fitted with independent electrical motors, which had been a matter of considerable professional interest.

He became a member of this Society at its Providence meeting, June, 1891, and died of pneumonia, September 3, 1893.

ARTHUR F. WENDT.

Arthur F. Wendt was born in Milwaukee, Wis., November 24, 1852. He entered Union College in 1867, at Schenectady, N. Y., but after the first year he decided to take up mining engineering as a profession, and entered the recently established School of Mines of Columbia College, New York City, where he received the degrees of C.E. and M.E. in 1872 and 1874, respectively, and the scientific degree of Ph.D. in 1883. During the period of 1873 and 1874 he was assistant chief engineer of West Point Foundry, but his later work was mainly metallurgical, and includes the design and erection of the dressing plant and smelter for the Lake George Antimony Company; the mining plant and smelter for copper at Ducktown, Tenn; the iron dressing and mining plant for the Crown Point Iron Company and the Mahopac Iron Ore Company; the blast furnace for the Lehigh Zinc and Iron Company and the Passaic Zinc Company.

In 1885 he went to Bolivia, and his latest and best known works were done in that country. He put up the mill, smelting works and mining plant of the famous Potosi Silver Mines, and his death was really brought about by the strain of the designing and erection of these immense works for ores of the Huanchaca Silver Mines, the cost and equipment of which being said to exceed $2,000,000. Photographs of these works were on exhibition at the Columbian Exhibition at Chicago in 1893.

Mr. Wendt attached himself to the Society at the New York meeting in 1889, and died at Charlottenberg, Germany, at the baths of Wildungen, whither he had gone in an effort to seek restoration of health.

WILLIAM THOMAS NICHOLSON.

William Thomas Nicholson was born at Pawtucket, R. I., the son of a mechanic, March 22, 1834. In early life his parents moved to Whitinsville, Mass., where he received his education at the village school and at the Uxbridge Academy. He learned his trade in a small shop, which in later years developed into the Whitins Machine Shops, now so widely known as builders of textile machinery.

Dissatisfied with the limited field at home, he early left Whitinsville and went to Pawtucket, where he worked a while as a machinist. He next moved to Providence, R. I., where he made his home for the rest of his life. After working a short time in several shops, he, in 1852, entered the employ of Joseph R. Brown, who at that time did a business in repairing watches and clocks, and kept four or five mechanics at work repairing and building special machinery. These workmen Mr. Nicholson was soon put in charge of, and their number gradually increased to some thirty at the time of his starting in business for himself.

Upon Mr. Brown's forming the copartnership of Brown & Sharp, Mr. Nicholson resigned his position and started in business on his own account, having associated with him Isaac Brownell. This change did not disturb the friendship which existed between himself and Mr. Brown and which continued until the death of the latter.

Dissatisfied with a partner, Mr. Nicholson bought out his interest and enlarged his machine shop. Here he met reverses, but some contracts for small parts for the Springfield rifle were secured and a special partnership formed with Henry A. Monroe

to carry on this particular branch. Much special machinery had to be devised, but the undertaking proved profitable.

Believing that the war would end, Mr. Nicholson closed out his interests in the government work to his partner, and from that time devoted his energies almost entirely to file manufacturing. In 1864 he formed the Nicholson File Company, with a capital of $300,000, and to this company he sold his machine-shop plant, which was put at work building file machinery.

While in the machine business he made several inventions, among which are the taper pin locking device, now so generally used on turret lathes; an egg-beater, which at one time had a large sale; a machinists' vise with hardened steel jaws; a metal spirit-level, still known and sold as Nicholson's level, and a machine for cutting file teeth. This latter invention was a good while developing, and the first machine was kept in a secret room very quietly, and only a chosen few were permitted to view it until after the file works were in operation. While the machinery was being built and the buildings completed Mr. Nicholson made a trip to Europe to study the conditions of the file industry there—England, and particularly Sheffield and vicinity, which was then the manufacturer of the bulk of files used throughout the world. Here he spent considerable time.

The English file workmen, however, were so set against the introduction of any machinery that they would not work in a factory using any; and Mr. Nicholson secured two machines for grinding files, which he brought home with him.

Upon his return to Providence he commenced the manufacture of files, having his cutting machines and the two English grinding machines. These latter showed defects, which resulted in Mr. Nicholson's inventing a machine of his own for file grinding, which machine has needed but little improvement in a quarter of a century.

The hope of the Nicholson File Company was that a capacity of three hundred dozen daily might ultimately be obtained. Mr. Nicholson lived to see a plant with a capacity of ten times this production, so that its capital was twice increased. He married in 1857, and became a member of this Society in its early days of formation. He passed away October 17, 1893.

He spent three years in politics; and he was also a trustee and director of many interests outside of his business in the city of Providence, which was his home.

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